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STRUCTURAL ANALYSIS OF A VANE FOR AN ADVANCED ENVIRONMENTAL CON--ETC(U)

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STRUCTURAL ANALYSIS OF A VANE FOR AN ADVANCED ENVIRONMENTAL CONTROL SYSTEM ROTARY VANED COMPRESSOR

KENNETH P. SCHWARTZ
MECHANICAL BRANCH
VEHICLE EQUIPMENT DIVISION

JUNE 1977

TECHNICAL REPORT AFFDL-TR-77-49
Final Report for Period February 1976 to February 1977

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FOR THE COMMANDER:

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The primary intent of this effort was to determine if the existing ROVAC vane could be improved from a total weight, operational bearing loads, and vane tip deflection point of view. To attain these improvements the use of advanced filamentary composite materials was suggested and was studied ~~then analyzed in detail.~~

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The analysis ~~conducted~~ consisted of the generating of an automated vane modeling (AVM) computer program from which a NASTRAN finite element model of the ROVAC vane could be modeled. Through the use of the AVM program, then, 22 design variations and materials substitutions were set up and analyzed by means of NASTRAN. Specifically the analysis involved 10 runs in which 9 advanced composite layups were compared against the baseline ROVAC vane. Following this survey the ROVAC vane axles (FDL-1 design) and vane axles and boots (FDL-2 design) were removed for further design improvements. Overall, the results of the study were very positive. Bearing loads were reduced from 975 lbs to 801 and 676 lbs for the FDL-1 and FDL-2 designs, respectively. They were then further reduced to 328 lbs by thinning the vane down to 40% of its original thickness. For these same design changes, vane-tip deflections were reduced from 2.91 mils to 1.11 and 1.06 mils for the FDL-1 and FDL-2 carbon graphite designs, respectively. They were further reduced to .9 mils for the 40% thick design. In regard to actual vane weight the following improvements were noted: Basic ROVAC Vane = .942 lbs, FDL-1 = .772 lbs, FDL-2 = .608 lbs, and the FDL-2 (40% thick) = .323 lbs. In addition to the above, overall vane stresses were also reduced by 40% to 60% and vane-edge deflections were reduced by 70%.

FOREWORD

The analysis conducted in this report was performed in-house by the Mechanical Branch, Vehicle Equipment Division, of the Air Force Flight Dynamics Laboratory. The effort is part of an FEM Support program (to FEE) to obtain increased capacities, and performance improvements in the area of aircraft environmental control systems. This effort was performed under Project 61460225, currently under the FEE thermal control group. The analysis was conducted from February 1976 to February 1977 by Kenneth P. Schwartz of the Air Force Flight Dynamics Laboratory (AFFDL/FEM).

Special acknowledgment goes to Mrs. S. Foley (4950/ADDP) for her timely programming assistance in this effort.

This report was submitted by the author in March 1977.

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SECTION I

INTRODUCTION

For some time now, the AFFDL has been investigating the use of rotary-vaned positive-displacement air-cycle machines for aircraft environmental control systems. The selection of a rotary-vaned unit is based on the assumption that a positive displacement unit of this type is capable of operating more efficiently than conventional turbomachinery at the low flow rates required to cool distributed small heat loads.

Preliminary rotary cooler studies were undertaken with two major objectives in mind: (1) to identify the most promising combination of rotary machine and equipment arrangement for meeting the cooler requirements, and (2) to identify any significant problem areas and possible solution approaches.

Two types of rotary positive-displacement machinery were considered during previous investigations; they were the single-rotor sliding-vane type of machine, and the two-rotor fixed-vane machine. Although there are a number of different machinery designs which use the basic sliding-vane principle, only one design configuration (herein referred to as the ROVAC machine) was considered for the rotary cooler application. Likewise, only one configuration of the two-rotor fixed-vane machine was considered. These two machines had considerably different mechanical features and thus provided a reasonable basis for initial assessment of machinery viability for the rotary cooler application.

Ultimately, a sliding-vane or ROVAC machine was selected. Schematic drawings of the ROVAC sliding-vane machine are shown in Figures 1 and 2. The machine consists of a circular slotted rotor, concentrically positioned in the elliptical bore of a stationary housing. Sliding vanes in the rotor slots divide the space between rotor OD and housing bore into a number of small spaces (cylinders) whose volumes vary as the rotor turns. On one side of the bore's minor axis these variable volumes are used to accomplish positive displacement compression; on

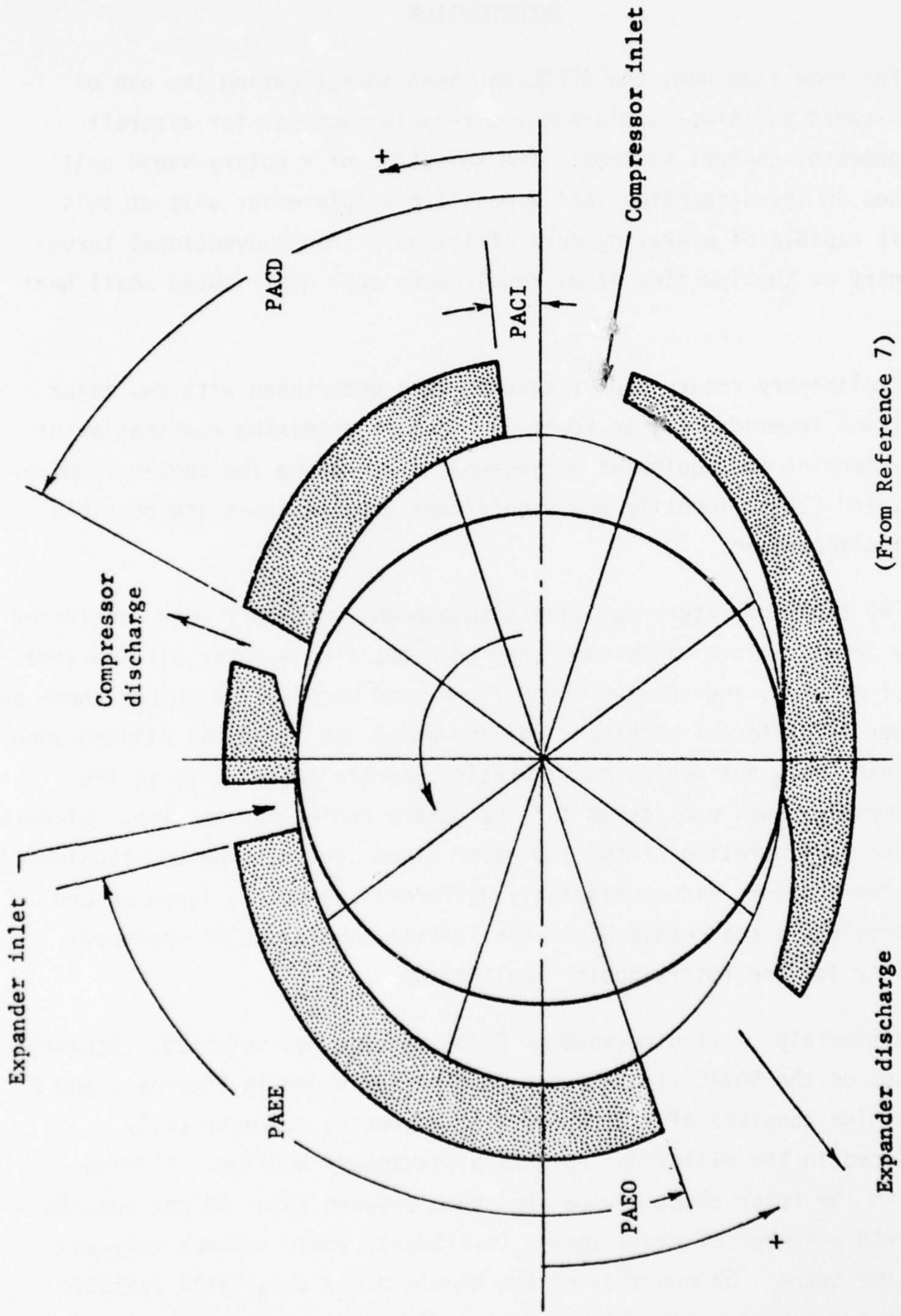

Figure 1. Schematic of ROVAC Machine (From Reference 7)

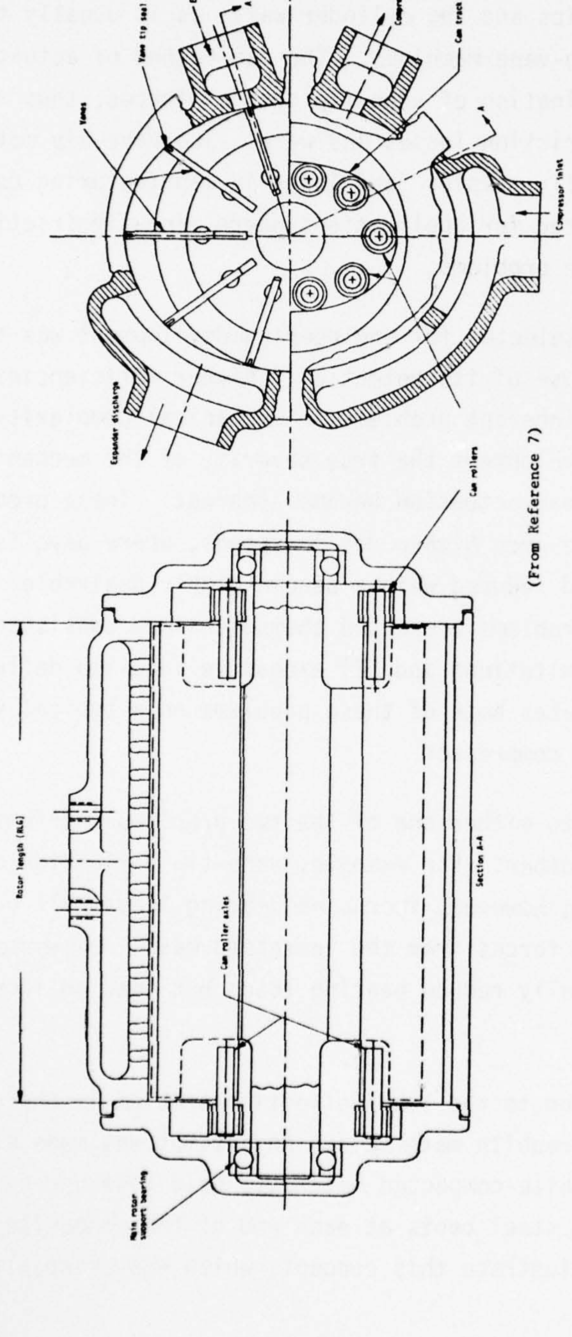

Figure 2. Assembly Schematic of ROVAC Machine

(From Reference 7)

the other side of the minor axis the variable volumes perform positive displacement expansion. As depicted in Figure 2, cams and cam rollers at the two ends of the rotor can be used to actuate the sliding vanes within the rotor slots. Or, vane actuation may be achieved via contact forces between the vane tips and the cylinder wall, as is usually the case in commercial sliding-vane machines. The cam method of actuation permits reduction or elimination of vane-tip contact forces, thus reducing or eliminating vane-tip friction losses and wear. The vane-tip method of actuation is mechanically simpler (and lower in manufacturing cost) and will usually be selected for applications where vane-tip friction and wear do not present severe problems.

The ultimate method selected for engineering development was the cam actuation method because of its potentially higher efficiencies. However, this method has inherent problems in mechanical complexity. Within the engineering development the true severity of the mechanical problems associated with cam actuation became apparent. These problems are especially true at the even higher design speeds, where payoffs in increased efficiencies and reduced weight become highly desirable. Basically, two distinct problems presented themselves and consisted of: (1) bearing load/speed limitations and (2) excessive vane-tip deflection values. Figure 3 illustrates both of these problems on a typical vane for use in a cam-actuated compressor.

The normal solution to either one of the two problems inherently leads to compounding the other. For example, vane-tip deflection can be reduced via heavier vanes; however, increased bearing loads will occur due to higher centrifugal forces from the increased mass. Conversely, reduced vane masses generally reduce bearing loads but lead to increased tip deflections.

One potential solution to the load/deflection problem is the use of advanced low-density graphite materials. An attempt was made at this through the use of a graphite-compacted material, held together by means of two axles and a set of steel boots at each end of the composite structure. Figures 4 and 5 illustrate this concept, which was eventually fabricated and tested.

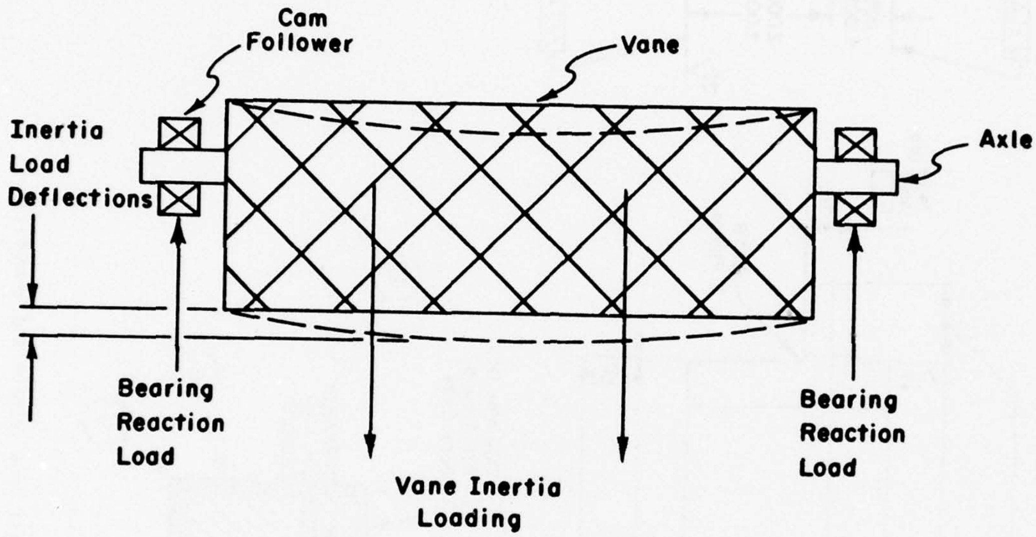

Figure 3. ROVAC Vane Loading and Deflections

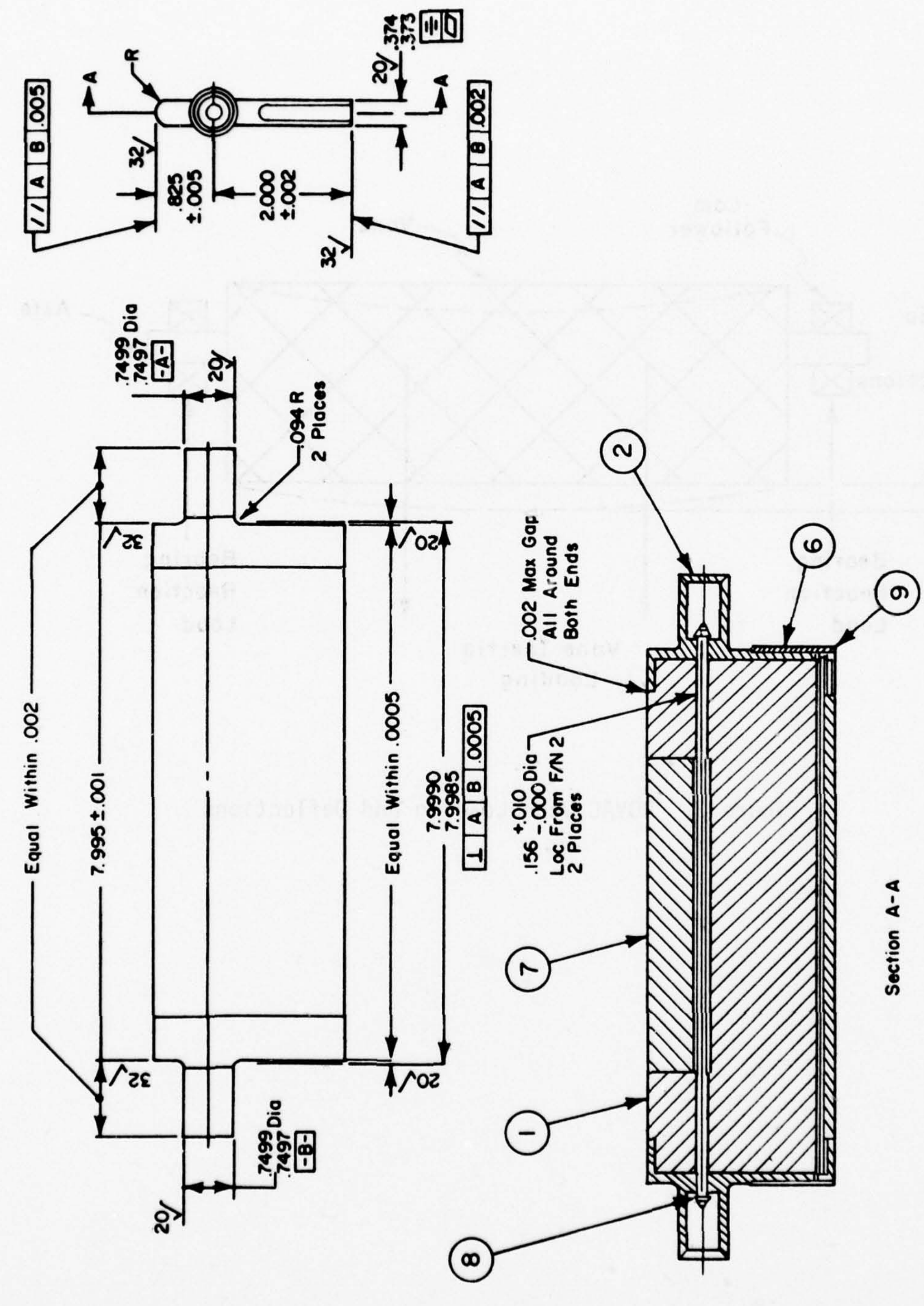

Figure 4. ROVAC Test Vane (Design and Assembly)

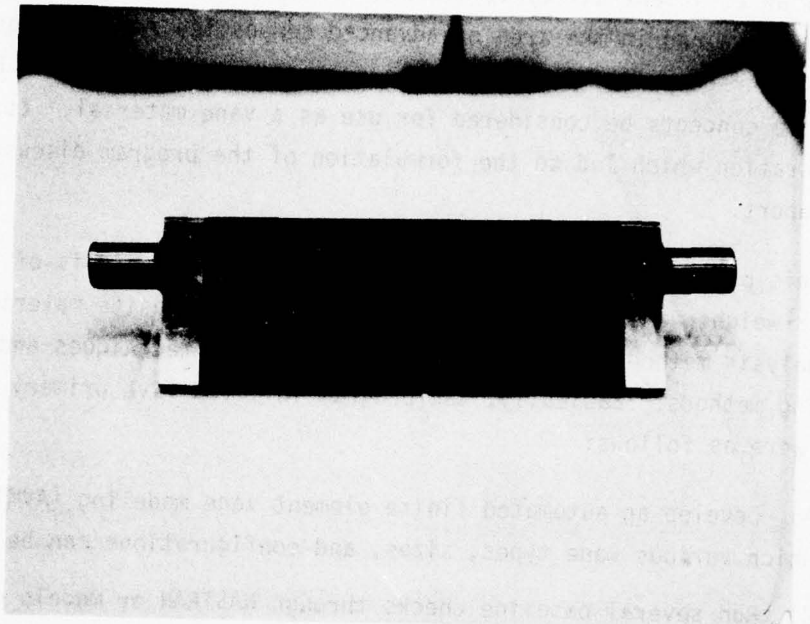

Figure 5. ROVAC Vane Photo

Although the above concept did offer some improvement, load/deflection problems were still prevalent and were severely inhibiting the development of an efficient air-cycle machine. Based on similar problems and experience gained in the area of advanced composites for bearings and landing-gear-component design, it was suggested that advanced filamentary composite concepts be considered for use as a vane material. It is this consideration which led to the formulation of the program discussed within this report.

This program is directed toward the design and analysis of various lighter weight vane concepts employing advanced composite materials. The analysis methods used employed finite element techniques and refined modeling methods. Basically, the program involved five primary objectives which were as follows:

A) Develop an automated finite element vane modeling (AVM) program from which various vane types, sizes, and configurations can be modeled.

B) Run several baseline checks through NASTRAN or models generated by means of the AVM program. These models will consist of the base graphite-compact vane (Figures 4 and 5) to which analysis results can be compared to available analytical and experimental results on the vane itself.

C) Run eight direct composite-substitution analysis surveys to determine the effects of using advanced composites within the vane in its current design state.

D) Run several additional composite runs beyond the current design state whereby the negative effects of incorporating steel boots and axles might be eliminated.

E) Based on the results of C and D above, conduct a series of runs incorporating vane thickness variations on the two most promising designs.

SECTION II

NASTRAN MODELING PROGRAM

Based on previous efforts in the area, the requirement for some form of automated data generator became quite obvious. Two primary reasons existed which determined this requirement and the approach to be selected for the automated data-generation system. The first was the fact that the sizing of the air-cycle machine itself involves developmental changes along with changes in vane dimensions and sizes. As a result, by the time one vane could be set up manually, the data itself became obsolete. The second and most important reason was the fact that, through a manual mode of data generation, little other than design verification studies could be made within the time frames involved. Studies of this type were very beneficial but what was really required were parametric analysis surveys where design changes could be studied and actually implemented.

The actual parametric data-generation system, herein referred to as the AVM (Automated Vane Modeling) program, employed in this effort involves a total of eight parameters which can be varied in the automated mode. These are as follows:

1. The ability to responsively change the basic dimensions of the vane itself.
2. The ability to vary the level of detail of the analysis effort (course versus refined finite-element models).
3. The ability to incorporate materials changes for the basic vane itself.
4. The ability to introduce materials variations (multi-materials) within the design of a single vane.
5. The ability to include the use of advanced composites for reductions in vane weight.
6. The ability to vary the method of bearing attachment to the vane.

7. The ability to vary the method of load transmission through the vane by either double axles, a single axle, or only a partial axle.

8. The ability to automatically include and vary all of the symmetric boundary constraints, rotational force vectors, panel inertia variables, and vane loading and reaction boundary conditions.

1. BASIC MODEL

The AVM program developed for this effort consists of generating the required NASTRAN input for seven basic data sets. Specifically, these include the "GRID" set, "CQUAD2" set, "SPC1" and "SPCADD" set involving both "RFORCE" (rotational forces), "GRAV" (Inertia forces) and miscellaneous external forces to the vane.

The basic model itself consists of a rectangular area (Figure 6) divided into a set of NPX (x projection) and NPY (y projection) lines. Typically, this results in a model involving a total of (NPX) (NPY) nodes in the structural analysis model.

To meet the eight requirements of the study, the uniform distribution noted in Figure 6 was further developed to a point where the actual x and y values for each x or y projection are individually input. A typical resulting model based on this setup is further illustrated in Figure 7 along with the element idealization.

2. "GRID" DATA SET

In accordance with the required NASTRAN input format, the following data is included for each grid point within the model.

ITEM NO.	1	2	3	4	5	6	7	8
COL. LOC.	1-8	9-16	17-24	25-32	33-40	41-48	49-56	57-64
VARIABLE	GRID	ID	CP	x	y	z	CD	PS

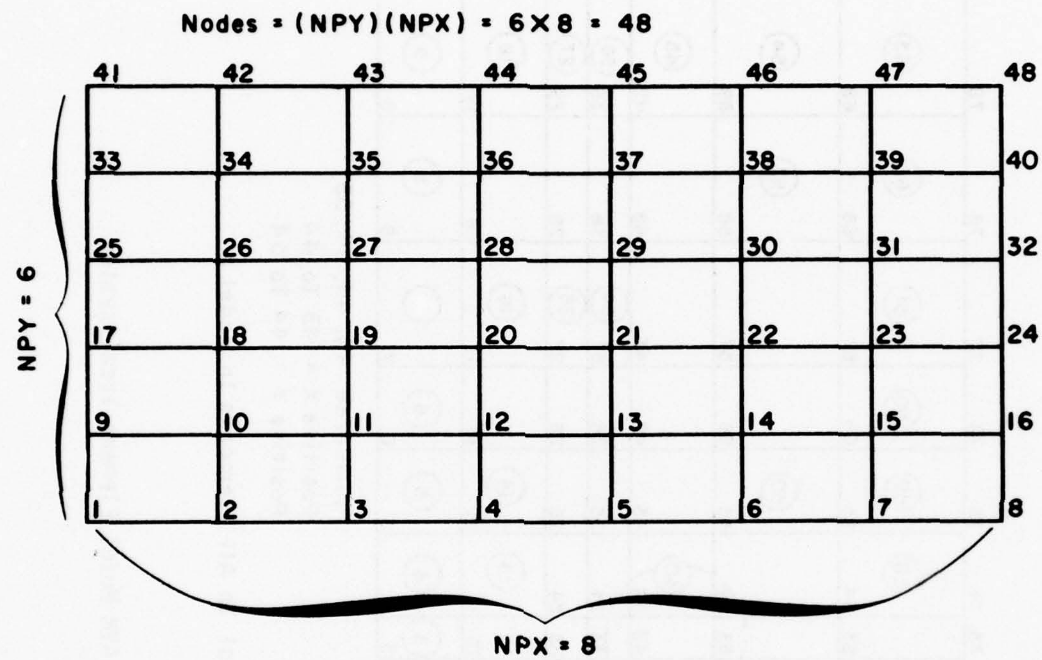

Figure 6. Basic AVM Nodal Arrangement

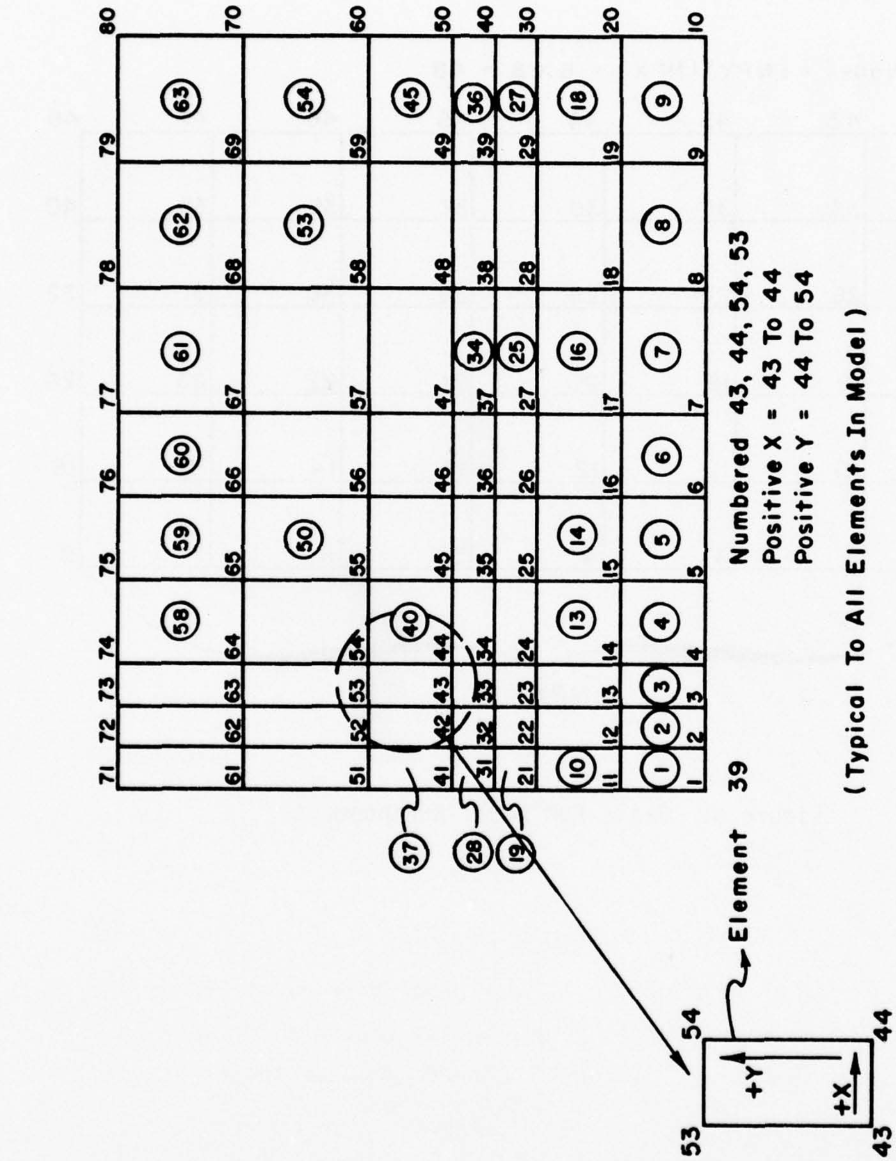

Figure 7. AVM Model Element Idealization

Item 1 - Alpha Name Grid
Item 2 - Grid Point Number (integer)
Item 3 - Blank (for ROVAC case)
Item 4, Item 5, Item 6 - x, y, z values for Node Point (Floating Point)
Item 7, Item 8 - Blank Fields (for ROVAC case)

3. "CQUAD2" DATA SET

It is within the "CQUAD2" set where the material properties, property variations (multi-materials per vane), and the use of advanced composites are introduced into the vane model. Specifically, these parameters are noted as variables PID and TH on the following NASTRAN data set.

ITEM NO.	1	2	3	4	5	6	7	8
COL. LOC.	1-8	9-16	17-24	25-32	33-40	41-48	49-56	57-64
VARIABLE	CQUAD2	EID	PID	G1	G2	G3	G4	TH

Item 1 - Alphanumeric name "CQUAD2"
Item 2 - Element identification no. (EID) (integer)
Item 3 - Property identification no. (PID) (integer)
(See following PID discussion)
Item 4, Item 5, Item 6, Item 7 - Nodal or grid point connection data for element no. EID Numbering starts at lower left and proceeds counterclockwise around element (integers)
Item 8 - Material property orientation angle for advanced composite type materials (see following TH discussion)

4. PROPERTY IDENTIFICATION DETERMINATION (PID)

Within a typical ROVAC vane, various properties exist across the vane surface in the form of end plates, boots, adaptors, or varying materials within the structure itself. To accommodate these changes,

the AVM program was set up to include four primary property areas. Typically, these property areas are noted in Figure 8 as PID values 1 through 4,

where:

X_{AP}, X_{BP}, X_{CP}, X_{DP}, and X_{EP} = input values (floating point)
(FORTRAN input = XP1 through XP5)

All CQUADS lying between X_{AP} and X_{BP} will have PID = 1

All CQUADS lying between X_{BP} and X_{CP} will have PID = 2

All CQUADS lying between X_{CP} and X_{DP} will have PID = 3

All CQUADS lying between X_{DP} and X_{EP} will have PID = 4

5. THETA DETERMINATION (TH)

One very promising method of significantly reducing the vane weight within an air-cycle system is through the use of advanced composite materials. To include the possibility for considering materials of this type, a total of four theta regions is included for automated setup on the ROVAC vane model. Typically, these regions are shown in Figure 9 as TH (or theta) values TH1 ... TH4,

where:

X_{ATH}, X_{BTH}, X_{CTH}, X_{DTH}, X_{ETH} = input values (floating point)

TH1, TH2, TH3, TH4 = input values (floating point)
(FORTRAN input = XTH1 through XTH5
(and TH1 through TH4)

All CQUADS lying between X_{ATH} and X_{BTH} will have TH = TH1

X_{BTH} and X_{CTH} will have TH = TH2

X_{CTH} and X_{DTH} will have TH = TH3

X_{DTH} and X_{ETH} will have TH = TH4

where TH1 ... TH4 = θ_1 .... θ_4
= material property orientation angles defining at which angle the anisotropic or orthotropic properties are related.

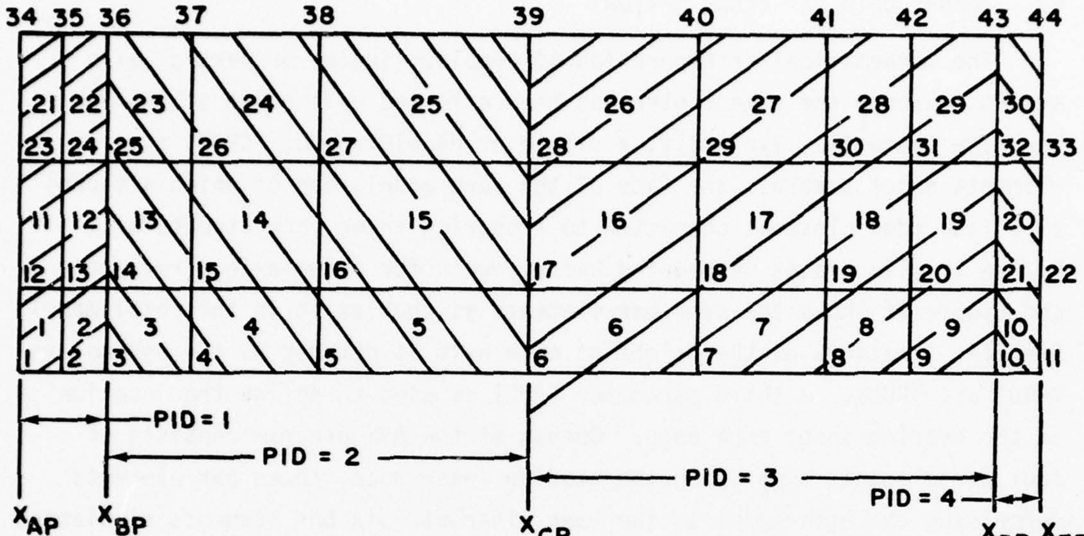

Figure 8. AVM Model Property Identification

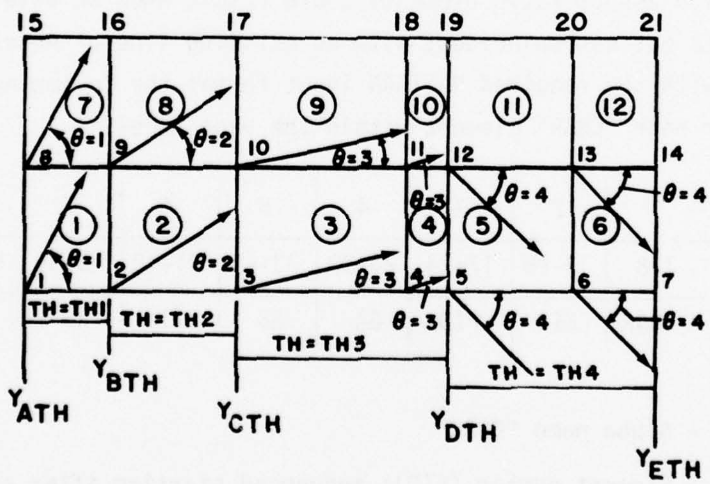

Figure 9. AVM Model Theta Relationship

6. "CBAR" DATA SET (EDGE OPTION)

The mathematical incorporation of double, single, or partial axle systems through the vane center has been effected by the use of NASTRAN bar type elements. Typically, a single or double row of "CBAR" type elements extends across the face of the vane model, one of which attaches to a vane edge closeout connected to a bearing inner race structure. Figure 10 illustrates segregated bar elements for a two-axle structure and Figure 11 shows the same bar elements as they exist in the total model. Specific locations of the height of each axle is defined by the parameters YROD1 and YROD2. A third parameter XROD1 is used to define the location of the bearing inner race edge. Output of the AVM program consists of four bar elements comprising the bearing inner race, three bar elements comprising the attachment to the vane closeout, six bar elements simulating the vane closeout stiffness, and a set of n-bar elements representing the upper and lower axles. In the event that either of the axle y positions do not fall coincident to an existing line of nodes (i.e., nodes 6, 7, 8, 9, 10, Figure 11) the AVM program will automatically generate a set of nodal points to which bar elements may be connected. It should be noted, however, that very high aspect ratio elements could result when an axle position is very close to but not coincident with an existing line of nodes. In accordance with the required NASTRAN input format the following data is included for each "CBAR" element within the vane model.

ITEM NO.	1	2	3	4	5	6	7	8	9
COL. LOC.	1-8	9-16	17-24	25-32	33-40	41-48	49-56	57-64	65-72
VARIABLE	CBAR	EID	PID	GA	GB	X1	X2	X3	F

Item 1 - Alpha name "CBAR"

Item 2 - Element number (EID); sequenced starting after all "CQUAD" elements have been numbered

Item 3 - Property identification number (see following PID discussion)

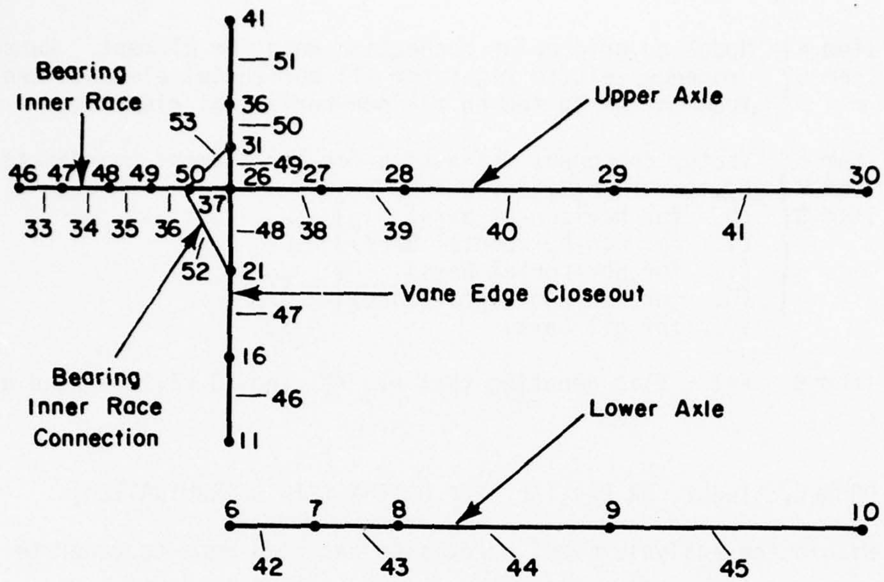

Figure 10. Segregated AVM Bar Elements For Double Axle

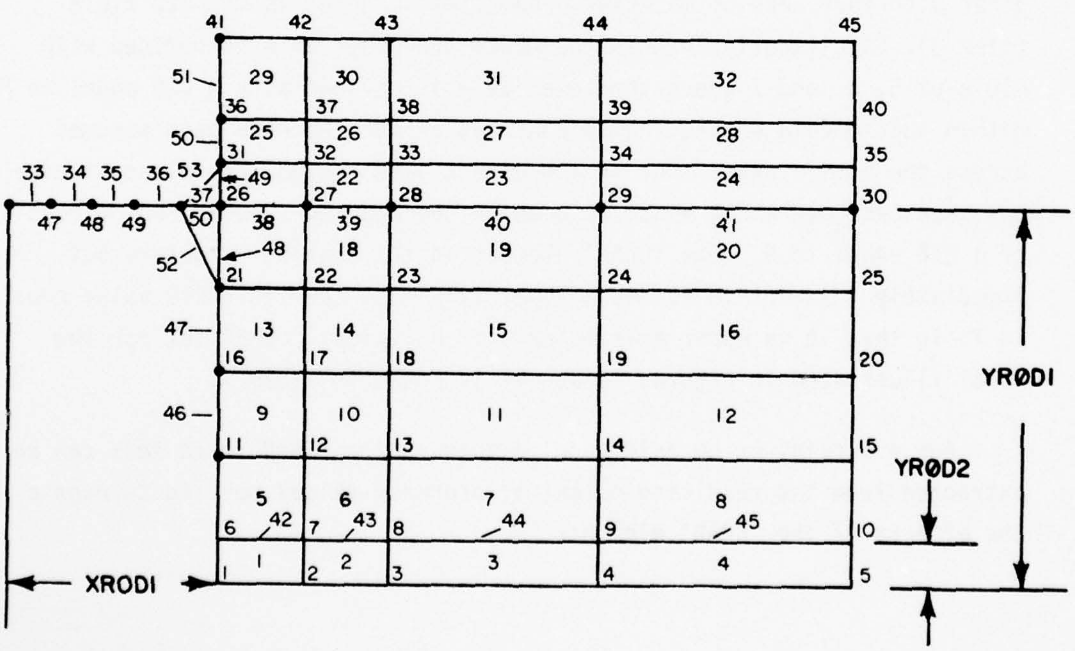

Figure 11. AVM Bar Elements Within Total Model

Item 4 Item 5	Nodal or grid point connection data for element. Numbering proceeds left to right for all horizontal elements and from bottom to top on all non-horizontal elements.
Item 6 Item 7 Item 8	Vector component definition for bar element coordinate system orientation. (0. for horizontal bars) (1. for non-horizontal bars) = X1 (1. for horizontal bars) (0. for non-horizontal bars) = X2 (0. for all bars) = X3
Item 9	F=1 = flag denoting that X1, X2, and X3 will be read as above

7. DOUBLE, SINGLE, OR PARTIAL AXLE OPTION (PID DETERMINATION)

Within the analysis model, provision has been made to generate either a single or double axle model. For the single axle, the upper bearing attachment axle will always be generated without the lower axle. Each of the two axles in the two-axle case have been set up independently of each other with four sets of material properties as noted in the PID field (Item 3). Specifically, within the model the upper axle is defined with PID's of 5, 6, and 7 where the lower axle is defined with a PID equal to 8. Within the immediate vane region constant properties have been assumed across the entire axle. Out of the direct vane region, the closeout edge has been assigned a PID equal to 6 while the bearing support region consists of a PID equal to 5. One "CBAR" element in the bearing structure but immediately adjacent to the vane upper axle also carries a PID value equal to 7, in that it is upper axle material. A typical "CBAR" set for the model illustrated in Figures 10 and 11 is noted in Table 1.

For a partial or no axle model either entire "CBAR" card sets can be extracted from the resulting output or property values revised to negate the effects of the "CBAR" elements.

TABLE 1

"CBAR" OUTPUT FOR FIGURES 10 AND 11

CBAR	33	5	46	47	0.00	1.00	0.00	1
CBAR	34	5	47	48	0.00	1.00	0.00	1
CBAR	35	5	48	49	0.00	1.00	0.00	1
CBAR	36	5	49	50	0.00	1.00	0.00	1
CBAR	37	7	50	26	0.00	1.00	0.00	1
CBAR	38	7	26	27	0.00	1.00	0.00	1
CBAR	39	7	27	28	0.00	1.00	0.00	1
CBAR	40	7	28	29	0.00	1.00	0.00	1
CBAR	41	7	29	30	0.00	1.00	0.00	1
CBAR	42	8	6	7	0.00	1.00	0.00	1
CBAR	43	8	7	8	0.00	1.00	0.00	1
CBAR	44	8	8	9	0.00	1.00	0.00	1
CBAR	45	8	9	10	0.00	1.00	0.00	1
CBAR	46	6	11	16	1.00	0.00	0.00	1
CBAR	47	6	16	21	1.00	0.00	0.00	1
CBAR	48	6	21	26	1.00	0.00	0.00	1
CBAR	49	6	26	31	1.00	0.00	0.00	1
CBAR	50	6	31	36	1.00	0.00	0.00	1
CBAR	51	6	36	41	1.00	0.00	0.00	1
CBAR	52	5	21	50	1.00	0.00	0.00	1
CBAR	53	5	50	31	1.00	0.00	0.00	1

8. "CBAR" SET (OPTION NON-EDGE)

In the previous axle model, an existing set of nodes along an existing y edge was used to define the axle bar elements or one was automatically generated. For some cases, however, it may be required that the axle be modeled across the centroid or some portion of the element other than the element edge. For the latter case, an entirely new set of nodal values is generated. Within the AVM program nodes may be suppressed and the generation of a line of non-edge nodes can be interchanged. Figure 12a illustrates this suppressed mode for a single axle non-edge generation scheme. Node points 51 through 55 have been added to the base model and from which the axle noted in Figure 12b was modeled. All of these nodes are totally independent of any element edge and truly lie across one of the existing elements in the structural model. It becomes obvious, however, that the axles modeled in this case are not inherent to the basic structural model. Some additional modeling will therefore be required to

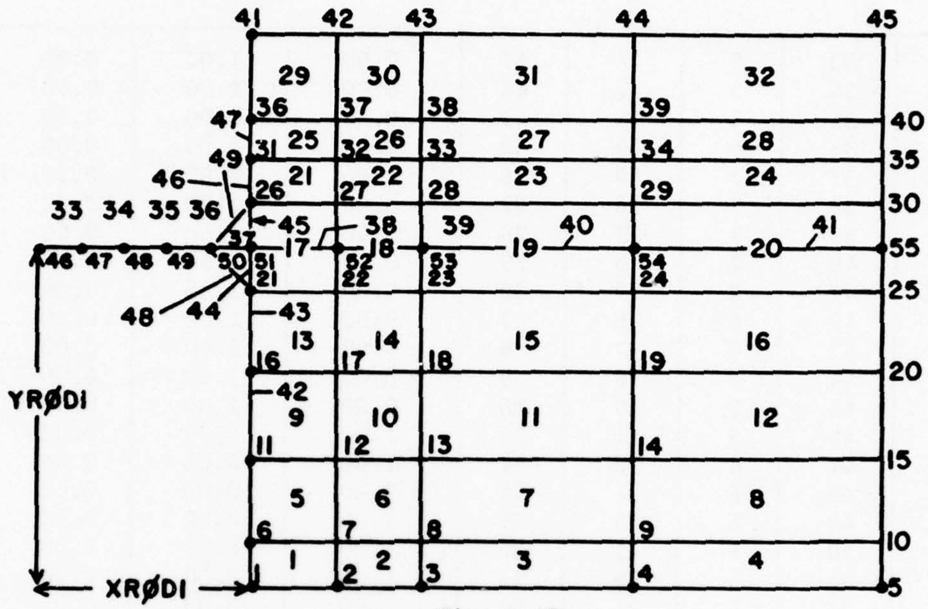

Figure 12a

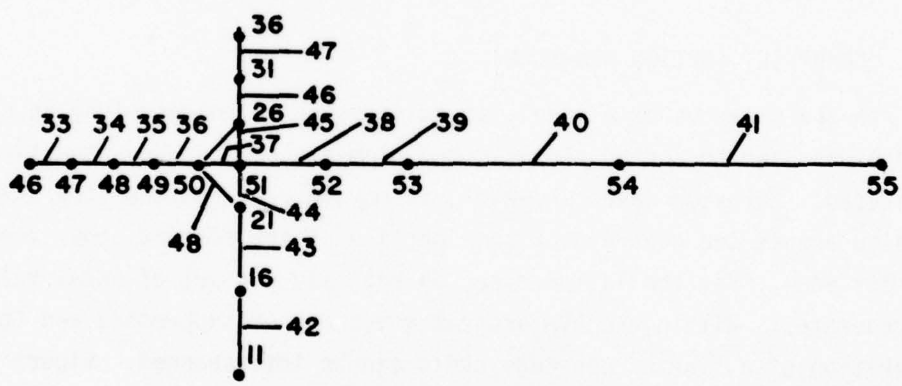

Figure 12b

Figure 12. Non-Edge, Single Axle Model

relate the axles to the model. This additional modeling has been left up to the user and has not been automated into the AVM program.

For the non-edge case, the vane closeout edge is modeled such that two bars are modeled across the left edge of the element divided by the axle. Two additional bars are generated above and below the inner race attachment points as is done in the edge case. All other modeling parameters are identical to the edge case.

9. "SPC" DATA SET (MATHEMATICAL CONSTRAINTS)

Within the AVM program various SPC (Single Point Constraint) sets are also generated. These sets include reaction points, unidirectional bearing constraints, M_z constraints, and symmetry constraints for symmetrical modeling. Each of these SPC sets is discussed in the following four sections.

a. Symmetry Condition

Due to the fact that the vane is symmetrically loaded and dimensionally identical about its centerline, only one half of the vane need be modeled. To effect this symmetry the AVM program selects the appropriate edge nodes along the centerline (Figure 13) and generates an appropriate NASTRAN "SPC1" card for each node point along this centerline edge. The actual constraints used resist both motion in the x direction and rotation about the y axis. The specific SPC1 format output is as follows:

ITEM No.	1	2	3	4	5
COL. LOC.	1-8	9-16	17-24	25-32	33 40
VARIABLE	SPC1	SID	C	G	D

Item 1 - Alphanumeric name "SPC1"

Item 2 - Constraint ID number, initialized at SID = 100 (integer) followed by consecutive +1 incrementing

Item 3 - Constraint factor no. 15 denoting a constraint in the 1 and 5 or X and M_y directions, respectively (integer)

Item 4 - Nodal point to be constrained (integer)

Item 5 - N/A (blank)

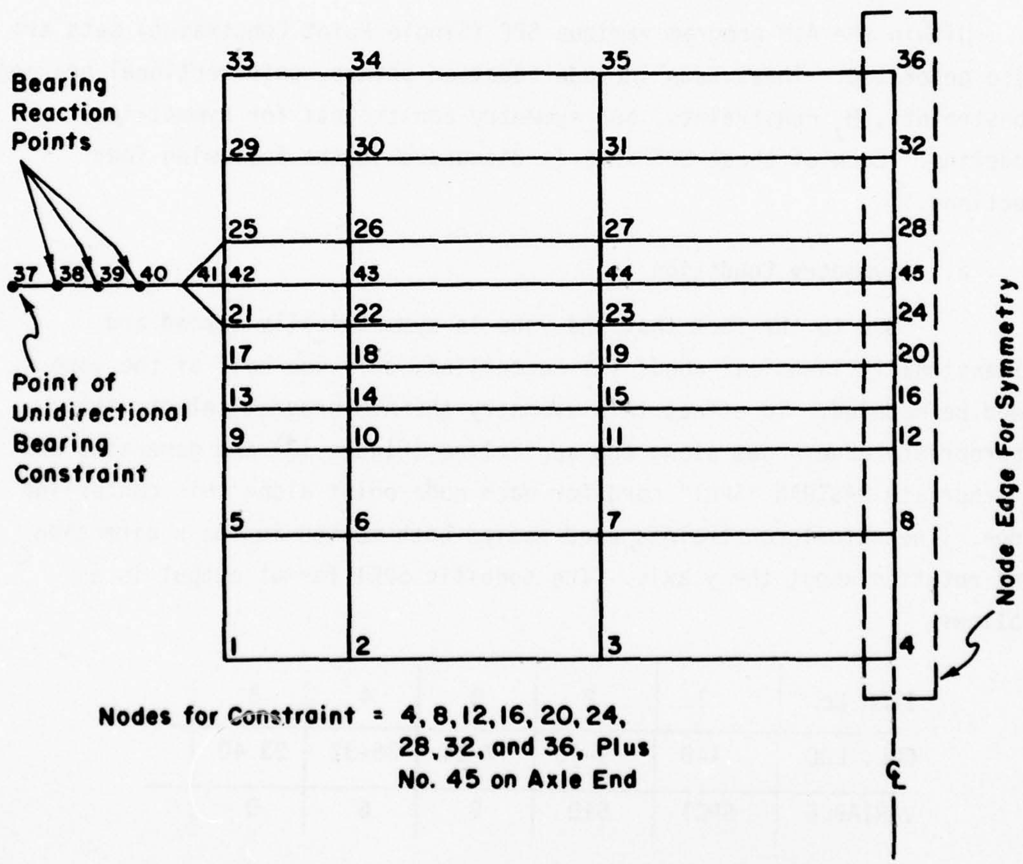

Figure 13. AVM Symmetrical SPC Set Definition

b. Unidirectional Bearing Constraint

Within the analysis model a "SPC1" constraint is generated representing the total restraint existing (in the y plane) at the bearing. At this point y motion is reacted by the ROVAC track, x motion is reacted by the machine end plates, M_x, and M_y are reacted through the rotor and z is fixed because of the y plane constraint. Typically, this bearing constraint is always applied to the left most nodal point (No. 37, Figure 13) on the inner race axle model. For this case, one "SPC1" card is generated with C = 123456. The assigned SPC set number for this card is 500.

c. Reaction Points

Primary loads within the ROVAC vane structure are generated from both rotational and linear inertia effects. Typically, these loads are reacted in the $\pm y$ direction at the bearing inner race mount. This mount in the automated generator consists of the four left most nodal points (i.e., 37 through 40, Figure 13). To satisfy the $\pm y$ reaction, three of these four points must be additionally constrained. This is accomplished through the use of a "SPC1" card containing all three points where C is set equal to 2. The SPC set number for this card is 502.

d. Z Axis Moment Constraint (M_z)

The standard "CQUAD2" NASTRAN M_z constraint set has been represented in the vane model by the SPC set number 501. Within this set all nodal points within the model are constrained in the R3 direction. A point of caution or possible error is presented at this point, in that those "CBAR" elements requiring M_z freedom could adversely be affected through this M_z SPC1 imposition. If this is the case, a separate hand-generated SPC1 set would have to be developed for M_z which would not include nodal points associated with any "CBAR" type elements.

e. Combined Constraints

All of the SPC sets generated for the vane model are combined into a single constraint set. This constraint set is assembled by means of the "SPCADD" card and continuation cards. The final resulting SPC set

for NASTRAN case control is SID = 99. Table 2 is a tabulation of all the SPC sets and SPC combination for the model noted in Figure 13.

TABLE 2

AVM GENERATED CONSTRAINT SET

SPC1	100	15	4						
SPC1	101	15	8						
SPC1	102	15	12						
SPC1	103	15	16						
SPC1	104	15	20						
SPC1	105	15	24						
SPC1	106	15	28						
SPC1	107	15	32						
SPC1	108	15	36						
SPC1	109	15	45						
SPC1	500	123456	37						
SPC1	501	6	1	THRU	45				
SPC1	502	2	38	39	40				
SPCADD	99	100	101	102	103	104	105	106	ABC10
+BC10	107	108	109	500	501	502			

(Reference Figure 13)

10. PROPERTY AND MATERIALS DATA

Quadrilateral properties within the ROVAC model are defined by means of "PQUAD2" cards representing each of the four vane areas previously discussed.

a. "PQUAD2" Data

The specific "PQUAD2" data output for the ROVAC vane model is as follows:

ITEM NO.	1	2	3	4
COL. LOC.	1-8	9-16	17-24	25-32
VARIABLE	PQUAD2	PID	MID	T

Item 1 - Alphanumeric name "PQUAD2"

Item 2 - Property identification no. (PID) (INTEGER)

Item 3 - Material identification no. (references a specific material card where the specific material properties are defined for the property identification (PID) (INTEGER)

Item 4 - Thickness of all elements relating to this property (Real Number)

b. "PBAR" Data

Bar element properties within the ROVAC model are defined by means of four "PBAR" cards representing each of the four axle or bearing-support regions previously discussed. Due to the fact that some of the properties are small and are self-computed by the automated data-generator program, a la~ge field card was required. The specific large field "PBAR" data output for the ROVAC vane model is on two cards as follows:

ITEM NO.	1	2	3	4	5	6
COL. LOC.	1-8	9-24	25-40	41-56	57-72	73-80
VARIABLE	PBAR*	PID	MID	A	I1	QABCDEF1

ITEM NO.	7	8	9
COL. LOC.	1-8	9-24	25-40
VARIABLE	*ABCDEF1	I2	J

Item 1 - Alphanumeric name "PBAR*" where the * flags a large field card and the following four fields of data on the card will be read in fields of 16 rather than 8.

Item 2 - Bar property identification number (PID) (Integer)

Item 3 - Material ID No. (Ref. PQUAD2 card)

Item 4 - Bar cross-sectional area (Real)

Item 5 - Area moment of inertia (Direction 1) (Real)

Item 6 - Coded continuation card flag

Item 7 - Continuation cards related to coded item number 6 (* = large field flag for items 8 and 9)

Item 8 - Area moment of inertia (Direction 2) (Real)

Item 9 - Torsional constant (Real)

c. "MAT1" Data

Each of the "PQUAD2" and "PBAR" cards noted previously contains a material identification number as Item 3. For the ROVAC vane each of these ID numbers is unique for each of the eight property cards. As a result, eight unique materials cards are required for the ROVAC model. Typically, each of these eight materials references are output as follows:

ITEM NO.	1	2	3	4	5	6	7
COL. LOC.	1-8	9-16	17-24	25-32	33-40	41-48	49-56
VARIABLE	MAT1	MID	E	G	MU	RHO	

Item 1 - Alphanumeric name "MAT1"

Item 2 - Materials property identification number per property card reference (Integer)

Item 3 - Young's modulus (Real)

Item 4 - Blank for ROVAC Case (computed within NASTRAN)

Item 5 - Poisson's ratio (Real)

Item 6 - Mass density (Real)

Item 7 - Blank for ROVAC model

11. ROVAC VANE LOADING

As stated previously, vane loads are generated from two primary sources, consisting of rotational and inertia forces generated during air-cycle machine operation. Specifically, the rotational forces result from pure rotor rotation, whereas the inertial force is added due to the effects of in and out movement of the vane through the rotation angle. To simulate these loading values in the ROVAC model, two distinct input sets are generated by the AVM program.

a. Rotational Force ("RFORCE")

The first load condition consists of a rotation force ("RFORCE") data set defining a static loading condition due to a centrifugal force field. Based on the mass properties of the model, a corresponding

centrifugal loading for each element in the model will be generated. The specific ROVAC AVM output for the "RFORCE" data is as follows:

ITEM NO.	1	2	3	4	5	6
COL. LOC.	1-8	9-24	25-40	41-56	57-72	73-80
VARIABLE	RFORCE*	SID	G	CID	A	QRFORCE1

ITEM NO.	7	8	9	10
COL. LOC.	1-8	9-16	17-24	25-32
VARIABLE	+RFORCE1	N1	N2	N3

Item 1 - Alpha name "RFORCE*" where the * flags a large field set and the following 4 fields of data will be read in fields of 16 rather than 8.

Item 2 - Unique load set identification number (Integer) (for ROVAC SID = 20).

Item 3 - Grid point identification number indicating a center of rotation for the ROVAC vane model (Integer).

Item 4 - Blank for ROVAC case indicating that the basic co-ordinate system defines the rotation direction.

Item 5 - Scale factor for rotational velocity in revolutions per unit time (ROVAC = rps).

Item 6 - Coded continuation card flag.

Item 7 - Continuation card related to coded Item No. 6.

Item 8, Item 9, Item 10 - Rectangular components of rotation direction vector (Real).

b. Inertia Loading ("GRAV")

The second load condition consists of a gravity vector "GRAV" data set defining a gravity vector simulating an inertia type loading for the ROVAC vane model. Based on the mass properties, then, a corresponding

inertia loading for each element in the model will be generated. The specific ROVAC AVM output for this "GRAV" data is as follows:

ITEM NO.	1	2	3	4	5	6
COL. LOC.	1-8	9-24	25-40	41-56	57-72	73-80
VARIABLE	GRAV*	SID	CID	G	N1	QGRAV1

ITEM NO.	7	8	9
COL. LOC.	1-8	9-16	17-24
VARIABLE	+GRAV1	N2	N3

Item 1 - Alpha name "GRAV*" where the * flags the large field set noted previously.

Item 2 - Unique load set identification number (Integer) (for ROVAC Case SID = 21).

Item 3 - Coordinate system identification number set to blank (0) for the ROVAC case. (References the basic coordinate system.)

Item 4 - Actual gravity vector value (Reference the following gravity vector discussion).

Item 5
Item 8 - Gravity vector components (Real).
Item 9

Item 6 - Coded continuation card flag.

Item 7 - Continuation card related to coded item No. 6.

c. Gravity Vector (Item 4)

Within the air-cycle machine, it was noted that the vane is traveling about an elliptical path, which results in an in-and-out translation of the vane itself throughout each rotational cycle. The magnitude and direction of this travel is of course controlled by the elliptical cam track and the slots within the rotor are as noted in Section I, Figures 1 and 2. As a result of this in-and-out vane motion at high rotor speeds,

a very significant inertia load is generated on the vane. In addition to this load, a friction load is further imposed as a result of the vane sliding in-and-out of the rotor slot. Both of these forces are represented within the AVM NASTRAN model by means of an acceleration or gravity vector value on a GRAV input card. The actual value of this vector can be derived from several sources or it could be computed from the machine geometrical parameters. The provision for computing the value is provided by means of eight input parameters ALDATA(1) through ALDATA(8). For this provision, the specific geometric equation would have to be added to the program. For the analysis conducted in this report, a representative input value was derived from an additional computer program which specifically analyzes the geometric relationship. The actual AVM input value is an acceleration value noted in inches per second.

d. Combined Loads

Both the "RFORCE" load and "GRAV" load sets are combined into a common load set through the use of a simple load card. For the ROVAC case, the rotational and gravity force sets have been identified as 20 and 21, respectively. The resulting combined load set has been identified as number 30 for NASTRAN case control. The specific ROVAC AVM output for the "LOAD" set is as follows:

ITEM NO..	1	2	3	4	5	6	7
COL. LOC.	1-8	9-16	17-24	25-32	33-40	41-48	49-56
VARIABLE	LOAD	SID	S	S1	L1	S2	L2

Item 1 - Alpha name "LOAD"

Item 2 - Load set ID number (SID - 30 for ROVAC AVM)

Item 3 - Scale factor for Item No. 2 load set (S = 1.000 for ROVAC AVM)

Item 5 } - Load set identification numbers to be combined into the SID
Item 7 } - set. For the ROVAC case, L1 = 20 and L2 = 21.

Item 4 } - Respective scale factors (S1, S2) for load sets (L1, L2).
Item 6 } - for ROVAC AVM S1 = S2 = 1.000.

e. Parameter Usage ("WTMASS" and "GRDPNT")

In accordance with NASTRAN requirements and desired ROVAC output two "PARAM" cards are generated by the AVM program. These include a grid point "GRDPNT" and a weight mass "WTMASS" parameter in accordance with the following:

	ITEM NO.	1	2	3
	COL. LOC.	1-8	9-16	17-24
CARD 1	VARIABLE	PARAM	WTMASS	.002588
CARD 2	VARIABLE	PARAM	GRDPNT	0

The weight mass parameter ("WTMASS") will result in all structural mass matrix terms being multiplied by the value contained in Item 3. For the ROVAC case, the mass parameter is 1/g, resulting in:

$$F = r\,\omega^2\,m = \frac{r\,\omega\,w}{g}$$

where

$1/g = 1/(32.2)(12) = .002588$ weight mass parameter
F = force
ω = angular velocity
r = radius

The grid point ("GRDPNT") parameter will result in the execution of the weight generator package where principal vane masses, centers of gravity, and inertias about the center of gravity will be generated. The value contained as Item 3 indicates the grid point to be used as a reference point for this information. For the AVM program, this value has been set at zero, and as a result the reference point is taken as the origin of the basic coordinate system.

f. Rotational Axis Definition

The generation of rotational forces for ROVAC studies require the definition of a rotational axis about which the vane shall rotate.

As noted previously in the RFORCE output, Item 3, (G) is required to define this axis specifically. The value G is a designated grid point lying on the axis of rotation from which the centrifugal force is derived. For the ROVAC AVM case, this grid point is an entirely independent point where:

$x = z = 0.0$

$y = y_0$ = AXIS

AXIS = distance from vane edge to the center of rotation

g. Program Termination

For program termination, the required "ENDDATA" card is self-generated within the ROVAC AVM program.

SECTION III

AVM PROGRAM INPUT AND OPERATION

As noted in the program listing contained in Appendix A, the AVM program consists of a main program called VANE and seven associated subroutines. These subroutines and their respective functions are as follows:

READIN - Program to simply read in and store all of the required program input data.

GRID - Program to generate all of the X-Y co-ordinate values associated with each nodal point within the structural model. (output to TAPE 7)

CQUAD2 - Program to calculate and set up all of the quadralateral elements within the finite element model. (output to TAPE 7)

LISTIN - Program to write out all input data and associated internally computed input values. (output to TAPE 6)

CBAR - Program to calculate and set up all of the bar elements within the finite element model. (output to TAPE 7)

CALCIN - Program to calculate and set up all of the PQUAD2, PBAR, MATI, SPC1 (500), SPC1 (501), SPC1 (502), RFORCE, GRAV, PARAM (WTMASS), PARAM (GRDPNT), GRID (Rotational), and ENDDATA cards required for the finite element analysis. (output to TAPE 7)

SPC - Program to calculate and set up all of the constraint cards required to model the symmetry conditions associated with the vane model. (output to TAPE 7)

a. Input Subscripts

AVM program input variables are generally related to eight sections or materials property areas contained within the model. Four of these areas are contained within the vane itself while the remaining four

are restricted to the vane axles. These eight areas are related to property variables within the program by means of subscripts or arrays numerically equivalent to the area number. Each of these eight areas is noted in Figure 14 and defined as follows:

A1 through A4 - Four areas across vane face (left to right where thickness, ρ, μ, E, and other properties may be varied).

A5 - Upper axle bearing-support area extending to the left of the axle transition area.

A6 - Axle transition and vane closeout areas located to the immediate left of the vane itself.

A7 - Upper axle extending through the vane and into the upper axle bearing-support area.

A8 - Lower axle area extending through the vane.

b. Computed Variables

Within the AVM program axle areas and axle area moments of inertia I_{xx} and I_{yy}) are self computed and automatically programmed into the NASTRAN output deck. The computations are based entirely on AVM input and are individually related to axle areas 5 through 8.

Within NASTRAN vane accelerations and inertia, forces are computed based on a vane speed in revolutions per second. The resulting NASTRAN output from the AVM program automatically accounts for these units. Gravity acceleration values can also be computed within the AVM program if desired. These values are based upon air-cycle machine design criteria as defined by AVM program input variables. The actual computation is based on input data noted as ALDATA (1) through ALDATA (8).

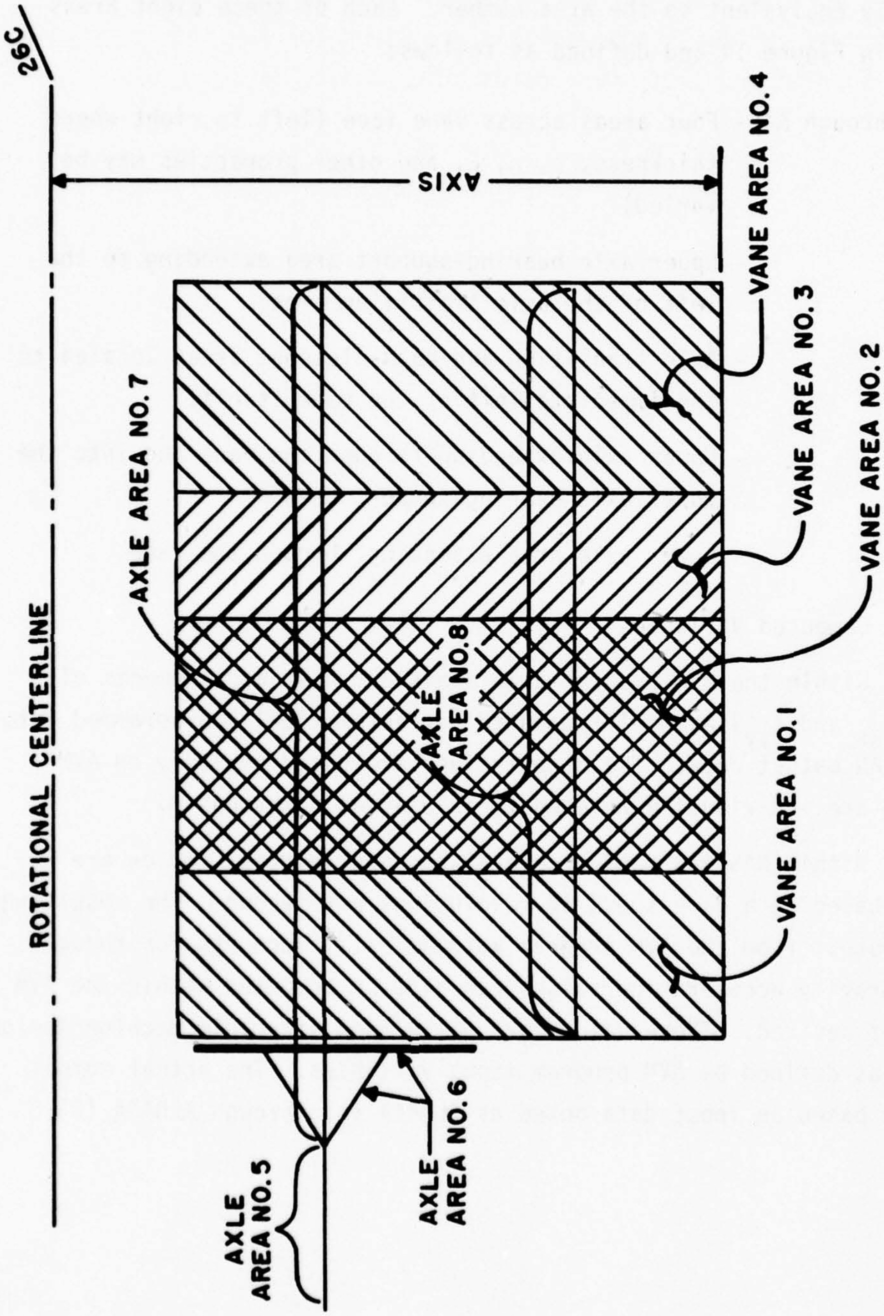

Figure 14. Vane and Axle Area Definition

c. Program Input

Input to the AVM program is accomplished by means of card or card sets containing all of the variables required for AVM program operation. Each of the individual cards or card sets is described as follows:

CARD 1 - INPUT VARIABLES = NPX, NPY, PRINT

FORMAT = 2I5, L1

NPX = number of points to be input along the X axis of the vane from which specific X values will be calculated for each nodal point.

NPY = same as NPX only for Y axis and Y values

PRINT = T or F value indicating whether or not an output listing of the program input is desired.

CARD 2 (SET) - INPUT VARIABLES = XIN(I) where I = 1 to NPX

FORMAT = 8F10.0

XIN = actual X values to be input for the X sectioning of the vane structure (values in inches).

CARD 3 (SET) - INPUT VARIABLES = YIN(I) where I = 1 to NPY

FORMAT = 8F10.0

YIN = actual Y values to be input for the Y sectioning of the vane structure (values in inches).

CARD 4 - INPUT VARIABLES = XP1, XP2, XP3, XP4, XP5

FORMAT = 8F10.0

XP1 through XP5 = 5 X values which divide the vane into four distinct areas for the future assignment of varying material properties across the vane face (values in inches).

CARD 5 - INPUT VARIABLES = XTH1, XTH2, XTH3, XTH4, XTH5

FORMAT = 8F10.0

XTH1 through XTH5 = 5 X values which divide the vane into four distinct areas for the future assignment of varying theta values defining material property orientation angles across the vane face (values in inches).

CARD 6 - INPUT VARIABLE = TH1, TH2, TH3, TH4

FORMAT = 8F10.0

TH1 through TH4 = actual property orientation angle (α) in each of the four areas defined by card number 4 (value in degrees as measured from an axis along the bottom of the vane from a leftwise origin where up is a positive value).

CARD 7 - INPUT VARIABLES - NROD, XROD1, YROD1, YROD2, NEOPTIN

FORMAT = I10, 3F10.0, I10

NROD = number of axles to be modeled within the vane structure (restricted to 1 or 2).

XROD1 = left most origin of the upper axle which defines the length of axle extending between the bearing and vane edge (value in inches).

YROD1 = distance of upper axle from the lower edge of the vane structure (value in inches).

YROD2 = distance of the lower axle from the lower edge of the vane structure (value in inches).

NEOPTIN = defines if the non-edge option is to be selected (any number greater than or equal to 1 will result in a non-edge model).

CARD 8 - INPUT VARIABLES - IFMT

FORMAT = I5

IFMT = flag indicating in what format the remaining data is to be read in. If IFMT is not equal to 1 the program will skip card sets 9 through 13. This option is for the input of more detailed properties in the format required for composite materials. The option currently is not in use and IFMT must be set equal to one (Value = 1).

CARD 9 - INPUT VARIABLE = XJ5, XJ6, XJ7, XJ8

FORMAT = 40X, 4F10.0

XJ5 through XJ8 = axle torsional constant in respective areas 5 through 8 as noted in Figure 9 (axle properties restricted to circular section).

CARD 10 - INPUT VARIABLES = THICK1, THICK2, THICK3, THICK4, RADIUS5, RADIUS6, RADIUS7, RADIUS8

FORMAT = 8F10.0

THICK1 through THICK4 = vane thickness values in respective vane areas 1 through 4 (values in inches)

RADIUS5 through RADIUS8 = Radius values of axle components as defined by the axle areas noted in Figure 9 (values in inches).

CARD 11 - INPUT VARIABLES - E1, E2, E3, E4, E5, E6, E7, E8

FORMAT = 8 (2X, A8)

E1 through E8 = modulus (E) values for vane areas 1 through 4 and axle areas 5 through 8. Input is in E format (i.e., 3.0E7 for steel)

CARD 12 - INPUT VARIABLES = XMU1, XMU2, XMU3, XMU4, XMU5, XMU6, XMU7, XMU8

FORMAT = 8F10.0

XMU1 through XMU8 = Poisson's Ratio values for vane areas 1 through 4 and axle areas 5 through 8.

CARD 13 - INPUT VARIABLES = RHO1, RHO2, RHO3, RHO4, RHO5, RHO6, RHO7, RHO8

FORMAT = 8F10.0

RHO1 through RHO8 = density values for vane areas 1 through 4 and axle areas 5 through 8 (values in lb/in^3.

CARD 14 - INPUT VARIABLES - VEL, AXIS, GRAV

FORMAT = EF10.0

VEL = compressor vane rotational velocity (value in revolutions per minute).

AXIS = distance from vane edge to center of rotation for compressor vane (value is in inches; ref. AXIS Figure 9).

GRAV = gravity acceleration value input at the option of the user. If GRAV is equal to zero, a gravity acceleration value based on the data supplied on Card No. 15 will be computed (value = in/sec^2).

CARD 15 - INPUT VARIABLES = ALDATA(1), ALDATA(2), ALDATA(3), ALDATA(4), ALDATA(5), ALDATA(6), ALDATA(7), ALDATA(8) (*)

FORMAT = 8F10.0

ALDATA(1) through ALDATA(8) = algorithm data variables 1 through 8 for computing the gravity acceleration value to simulate the vane forces due to the inertia effects resulting from the elliptical path or rotation within the air cycle machine. (*)

*Currently not set up within the AVM program (blank card required).

d. Data Summary

A complete summary of all associated input variables and input locations is presented in Table 3.

e. Test Cases

Four test cases were set up to check out the capabilities of the AVM program. Each of these cases is included in the section as sample I/O examples of the AVM program. AVM capabilities in addition to those noted in these four cases should be individually checked out by the user prior to running within NASTRAN.

CASE 1 Edge Model	-	Two-axle model where both the upper and lower axles fall on existing lines of nodes. (Bearing-support axle at bottom).
CASE 2 Self-Generating Edge	-	Two-axle model where the upper axle falls on an existing nodal line and the lower axle requires a self-generated edge. This model is also representative of an existing vane in an air cycle machine.
CASE 3 Non-Edge Option	-	Two-axle model where the lower axle is designed to fall between two nodal lines. For this case, a separate axle independent of the vane structure is generated resulting in 15 rows of elements rather than the 16 noted in Case No. 2.
CASE 4 Non-Edge Option with Cutout	-	Example application of a non-edge case where a model has been modified to include 3 cutout holes in the vane face.

f. Program Input/Output

Specific input data for each of the test cases 1 through 3 is noted in Table 4. Test case 4 is not included because this case simply extracted "CQUAD" and "GRID" cards from test case 3 output to simulate

TABLE 3

AVM INPUT DATA SUMMARY

CARD	COLUMN LOCATION								
SET	1-5	6-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
1	NPX	NPY	(PRINT)						
2	XIN1		XIN2	XIN3	XIN4	XIN5	XIN6	XIN7	XIN8
	XIN9		XIN10	XIN11	XIN12	XIN13	XIN14	....	XIN(NPX)
3	YIN1		YIN2	YIN3	YIN4	YIN5	YIN6	YIN7	YIN8
	YIN9		YIN10	YIN11	YIN12	YIN13	YIN14	....	YIN(NPY)
4	XP1		XP2	XP3	XP4	XP5			
5	XTH1		XTH2	XTH3	XTH4	XTH5			
6	TH1		TH2	TH3	TH4				
7	NROD		XROD1	YROD1	YROD2	NEOPTIN			
8	IFMT								
9						J5	J6	J7	J8
10	THICK1		THICK2	THICK3	THICK4	RADIUS5	RADIUS6	RADIUS7	RADIUS8
11	E1		E2	E3	E4	E5	E6	E7	E8
12	MU1		MU2	MU3	MU4	MU5	MU6	MU7	MU8
13	RHO1		RHO2	RHO3	RHO4	RHO5	RHO6	RHO7	RHO8
14	VEL		AXIS	GRAV					
15	ALDATA1		ALDATA2	ALDATA3	ALDATA4	ALDATA5	ALDATA6	ALDATA7	ALDATA8

TABLE 4

INPUT DATA FOR AVM TEST (CASES 1, 2, AND 3)

1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	Col.Loc.
14 10	T							
0.0	0.25	0.50	0.75	1.0	1.1	1.2	1.3	
1.4	1.5	1.75	2.0	2.25	2.5			
0.0	0.4	0.6	0.8	1.0	1.1	1.2	1.4	
1.6	1.8							
0.0	0.5	1.0	1.2	2.5				
0.0	0.5	1.0	1.2	2.5				
0.0	0.0	0.0	0.0					TEST CASE NO. 1
2	-1.0	0.4	1.2					
1								
				.75	.35	.35	.35	
0.75	0.75	0.75	0.75	.60	.90	.15	.15	
3.0E7	3.0E7	3.0E7	3.0E7	2.8E7	2.8E7	2.8E7	2.8E7	
0.25	0.25	0.25	0.25	0.30	0.30	0.30	0.30	
0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	
2000.	4.0	380000.						
0.0								

1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	Col.Loc.
28 16	T							
0.0	.07	.147	.2	.3	.4	.45	.5	
.55	.6	.652	.752	.852	.952	1.052	1.152	
1.3	1.5	1.75	2.	2.25	2.5	2.75	3.	
3.25	3.5	3.75	4.0					
0.	.2	.4	.6	.8	1.	1.2	1.4	
1.6	1.8	2.	2.2	2.4	2.6	2.7	2.825	
0.	.147	.652	2.	4.				
0.	.147	.652	2.	4.				TEST CASE NO. 2
0.	0.	0.	0.					
2	-.9	2.0	.17					
1								
				.4	.2	.125	.095	
.374	.374	.374	.374	.2	.1	.067	.0475	
3.0E7	1.0E7	3.5E6	3.5E6	3.0E7	3.0E7	3.0E7	3.0E7	
.32	.3	.28	.28	.32	.32	.32	.32	
.28	.15	.066	.066	.28	.28	.28	.28	
3100	5.5	380000.						
1.1	2.	3.	4.	5.	6.	7.	8.	

1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	Col.Loc.
28 16	T							
0.0	.07	.147	.2	.3	.4	.45	.5	
.55	.6	.652	.752	.852	.952	1.052	1.152	
1.3	1.5	1.75	2.	2.25	2.5	2.75	3.	
3.25	3.5	3.75	4.0					
0.	.2	.4	.6	.8	1.	1.2	1.4	
1.6	1.8	2.	2.2	2.4	2.6	2.7	2.825	
0.	.147	.652	2.	4.				
0.	.147	.652	2.	4.				TEST CASE NO. 3
0.	0.	0.	0.					
2	-.9	2.0	.17		2			
1								
				.4	.2	.125	.095	
.374	.374	.374	.374	.2	.1	.067	.0475	
3.0E7	1.0E7	3.5E6	3.5E6	3.0E7	3.0E7	3.0E7	3.0E7	
.32	.3	.28	.28	.32	.32	.32	.32	
.28	.15	.066	.066	.28	.28	.28	.28	
3100	5.5	380000.						
1.1	2.	3.	4.	5.	6.	7.	8.	

the lightning holes in an early ROVAC vane design. A final version of this No. 4 model with triangular elements added to the hole area is included in Appendix B.

Details as to element and nodal numbering for each of the test cases are noted in the twelve calcomp plots included in Appendix B. Also noted in this appendix are the abbreviated output listings for each of the test cases.

SECTION IV

VANE ANALYSIS SETUP

Twenty-two vanes (total) were setup within the program and analyzed by means of both NASTRAN and the AVM program. The overall analysis was conducted in three parts, which ranged from a very minimal design change to a total redesign of the vane itself. The first part consisted of a direct substitution analysis, whereby the ROVAC vane structure, with the associated bearing, bearing axle supports, and vane boot, was retained in its entirety. The second and third parts of the study involved the elimination of axles, boots, and vane thickness restrictions associated with the ROVAC vane design.

1. PART I (ROVAC AND ADVANCED COMPOSITES)

The Part I analysis consisted of ten NASTRAN models representing ten graphite fiber materials variations within the ROVAC vane design. For this design the concept of using a boot and axle system (Figures 4 and 5) was retained and varied orthotropic materials properties were introduced which effectively replaced the existing Graphite Compact vane. The ten materials considered within the analysis survey were as follows:

CASE 1 - A high strength (HS) layup consisting of 90% 0-degree fibers and 10% 90-degree fibers within the vane structure. The layup is totally symmetric with the 0-degree fiber being defined as a fiber lying across the length (8 inch section) of the vane. A 60% fill ratio was assumed.

CASE 2 - A high strength (HS) layup consisting of 10% 0-degree fibers and 90% 90-degree fibers within the vane structure. (90-degree rotation of test case 1 layup)

CASE 3 - A high strength (HS) layup consisting of $\pm$45-fibers throughout the entire vane thickness. The layup is totally symmetric and assumes a 60% fill ratio.

CASE 4 } - CASE 5 Each of these two cases is parallel to case No.'s 1 and 2 respectively. The only exception is that the high strength (HS) fiber (Cases 1 and 2) is replaced by a high modulus (HM) fiber for cases 4 and 5.

CASE 6 - Special higher yield version of Case 3.

CASE 7 - A 21 KSI fiber layup consisting of a unit symmetric layup involving three 0-degree layers, a +45-degree, a -45-degree layer, and one final 90-degree layer. Property data was derived by means based on fiber properties noted in Reference 6.

CASE 8 - A 90-degree rotation of the test case 7 layup.

CASE 9 - A compression-molded vane of chopped filaments; 21 KSI fibers were assumed and orientation is random, resulting in an isotropic block of vane material.

CASE 10 - Baseline case on which materials substitution was effected. Specifically, this consists of a sintered metal matrix carbon graphite compact material. The material is essentially isotropic in nature and can be modeled several ways within NASTRAN.

a. Basepoint Analysis (ROVAC, Case 10)

Prior to conducting a detailed materials substitution survey, a basepoint or baseline comparison analysis was conducted. The basepoint analysis consisted of the ROVAC graphite compact vane modeled through the use of isotropic NASTRAN MATI input cards. Several analysis checks and debug runs were required for each of the associated load subcases. A comparison of all analysis runs yielded good correlation and resulted in a final baseline run of a high confidence level. The basepoint analysis model consisted of an AVM two-axle system involving 482 gridpoints, 432 quadralateral elements, and 67 bar-type elements. The resulting basepoint model is illustrated in Appendix B Figures B-4 through B-6. A listing of the NASTRAN input with the exception of materials variation input is contained in Appendix C.

The overall results of the analysis compared quite favorably with both test results and computations from air-cycle machine analysis programs. Typically, bearing reactions, deflections, and vane shapes were very plausible values resulting in highly reliable stress/strain output for the analysis case. A summary of the results of the MAT1 final run are noted in the first row of Table 5.

A second basepoint run was also made for which a MAT2 input mode was used. This was done to validate the MAT2 input methods discussed in a later section of this report. The MAT2 results correlated very well, as can be noted in Table 5.

TABLE 5

BASELINE COMPARISON SUMMARY

	Lower Left Vane Deflect	Vane Center Deflection	Bearing Attch Deflection	Top Center Deflection	Bearing Load
MAT1 BASEPOINT	.000255	.00291	.0000707	.00298	971
MAT2 BASEPOINT	.000256	.00291	.0000707	.00298	975

(Deflections = inches, Load = lbs)

b. Advanced Composites Analysis

Basically this analysis consisted of nine NASTRAN runs, each involving a different set of MAT2 data which represented the varied orthotropic parameters for analysis cases 1 through 9. The first step of the analysis was to devise and tabulate the basic fiber, lamina, and laminate properties associated with the various analysis cases. This was accomplished by extracting basic filament or specimen data (References 1, 2, and 4) and applying this data to the SQ5 program (Reference 3) to obtain basic laminate properties. A summary of the extracted data and resulting SQ5 properties is contained in Table 6. From this data the basic bulk data G values required by NASTRAN can be derived for MAT2 input. A complete description of how the MAT2 values G_{11}, G_{12}, G_{13}, G_{22}, G_{23}, and G_{33}, were derived and run is included in the following discussion.

TABLE 6

ASSOCIATED FILAMENT AND LAMINATE PROPERTIES

	(ISOTROPIC) CARBON COMPACT	B .60 FILL HS-FIBER $[0_9/90]s$	C .60 FILL HS-FIBER [0]	D .60 FILL HS - FIBER [±45]	E .60 Fill HM-FIBER $[0_9/90]s$	F .60 FILL HM-FIBER [0]	G .60 FIL HM-FIBER [±45]	H .60 FILL AS-FIBER $[0_3/\pm45/90]s$ 21 KSI	I (ISOTROPIC) MOLDED CHOPPED GRAPHITE
E_y (Msi)	3.5	19.0	21.0	2.34	22.6	25.0	2.38	12.39	13.5
E_y (Msi)	3.5	3.6	1.7	2.34	4.1	1.7	2.38	6.23	13.5
G_{xy} (Msi)		.65	.65	5.52	.65	.65	6.46	2.27	5.2
M_{xy}	.28	.20	.21	.801	.26	.30	.83	.3028	.298
M_{yx}	.28	.0378	.017	.801	.0471	.020	.83	.152	.298
ρ (lbs/in^3)	.066	.056	.056	.056	.056	.056	.058	.056	
F_x^{TU}(Ksi)	8.0	163.0	180.0	23.2	99.0	110.0	16.9	75 **	34.0
F_y^{TU}(Ksi)	8.0	26.0	8.0	23.2	15.0	4.0	16.9	38 **	34.0
F_{yy}^{SU}(Ksi)	11.5	15.0	12.0	65.5	12.0	9.0	43.2	30 **	8.0
F_x^{CU}	39.0	163.0	180.0	23.9	92.0	100.0	18.0		52.0
F_y^{CU}	39.0	45.0	30.0	23.9	28.0	20.0	18.0		52.0

(X = XX = 11 = Longitudinal, Y = yy = 22 = Transverse)

**Extrapolated from $[0_3, \pm45, 90]s$ (Reference 6)

(1) MAT2 (NASTRAN Input)

The NASTRAN bulk data input for the anisotropic case consists of:

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix} = \begin{bmatrix} G_{11} & G_{12} & G_{13} \\ G_{12} & G_{22} & G_{23} \\ G_{13} & G_{23} & G_{33} \end{bmatrix} \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{Bmatrix} \tag{1}$$

The values associated with the above matrix are related through the Reference 2 equation:

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{xy} \\ \tau_{yz} \\ \tau_{xz} \end{Bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & Q_{13} & 0 & 0 & 0 \\ Q_{12} & Q_{22} & Q_{23} & 0 & 0 & 0 \\ Q_{13} & Q_{23} & Q_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & Q_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & Q_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & Q_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{xz} \end{Bmatrix} \tag{2}$$

where:

$$Q_{11} = \frac{E\,(1-\mu)}{(1+\mu)(1-2\mu)} \tag{2a}$$

$$Q_{12} = Q_{13} = Q_{23} = \frac{\mu\,E}{(1+\mu)(1-2\mu)} \tag{2b}$$

$$Q_{44} = G_{xy} \tag{2c}$$

$$Q_{55} = G_{yz} \tag{2d}$$

$$Q_{66} = G_{xz} \tag{2e}$$

and

$$\mu_{12}\,E_{22} = \mu_{21}\,E_{11} \tag{3}$$

The actual bulk data NASTRAN conversion consists of Equation 2 Q values and $G_{33} = G_{xy}$. Further restricting the vane to an in-plane $G_{13} = G_{23} = 0$,

from which Equation 1 becomes:

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix} = \begin{bmatrix} \dfrac{E_{11}}{1-\mu_{12}\mu_{21}} & \dfrac{\mu_{21}E_{11}}{1-\mu_{12}\mu_{21}} & 0 \\ \dfrac{\mu_{21}E_{11}}{1-\mu_{12}\mu_{21}} & \dfrac{E_{22}}{1-\mu_{12}\mu_{21}} & 0 \\ 0 & 0 & G_{xy} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} \tag{4}$$

(a) Analysis Case 1 (MAT2 Input)

For the case of $[0_9, 90]_5$ and from Table 6, which was prepared via composites program SQ5 (Reference 3), the following values are extracted: $E_{11} = 19.0(10^6)$, $E_{22} = 3.6(10^6)$, $G_{xy} = .65(10^6)$, and $\mu_{12} = .20$, $\mu_{21} = .0378$.

From Equations 1 and 4:

$$G_{11} = (10^6)19.0/[1-(.20)(.0378)] = 19.44(10^6)$$

$$G_{12} = (10^6)(.0378)(19.0)/.99244 = .724(10^6)$$

$$G_{22} = 3.6\ (10^6)/.99244 = 3.63(10^6)$$

$$G_{13} = G_{23} = 0$$

$$G_{33} = .65(10^6)$$

For the ROVAC AVM input the appropriate MAT2 input for Areas 3 and 4 is as follows:

ITEM NO.	1	2	3	4	5	6	7	8	9
COL. LOC.	1-8	9-16	17-24	25-32	33-40	41-48	49-56	57-64	65-72
VARIABLE	MAT2	MID	G11	G12	G13	G22	G23	G33	RHØ
Area 3 Input	MAT2	3	19.14+6	.724+6	-	3.63+6	-	.65+6	.056
Area 4 Input	MAT2	4	19.14+6	.724+6	-	3.63+6	-	.65+6	.056
Area 2 Input	MAT2	2	24.84+6	4.47+6	-	15.54+6	-	4.93+6	.146

Additional extrapolations or computations were utilized within the analysis for material Areas 1 and 2 (Figure 14). Area 1, being a steel edge of the vane boot, could be simulated by means of a MAT1 bulk data card. Since this was the case, no MAT2 computations were required, because the original MAT1 property card was retained. For Area 2, some form of anisotropic property has to be modeled to represent the boot which houses the composite vane. Typically, this was accomplished by assuming a 60/40 ratio of composite-to-steel structure from which modulus values were computed and checked by means of the SQ5 composites laminate program. Actual differences in modulus values between a direct proportioning method and SQ5 were very minimal. The resultant output is as follows:

$$E_{11} = 23.55(10^6),\ E_{22} = 14.74(10^6),\ G_{xy} = 4.93(10^6)$$

$$\mu_{12} = .288, \text{ and } \mu_{21} = .180 \text{ (reference Equation 3)},$$

from which (using Equations 1 and 4) we obtain:

$$G_{11} = \frac{E_{11}}{1-\mu_{12}\mu_{21}} = \frac{23.55}{.948} = 24.84(10^6)$$

$$G_{22} = \frac{E_{22}}{1-\mu_{12}\mu_{21}} = \frac{14.74}{.948} = 15.54(10^6)$$

$$G_{13} = G_{23} = 0$$

$$Q_{12} = \mu_{21}E_{11}$$

$$\text{or} = \mu_{12}E_{22} = (.29)(14.178)(10^6) = 4.11(10^6)$$

$$G_{12} = Q_{12}/1-\mu_{12}\mu_{21} = 4.47(10^6)$$

$$G_{33} = G_{xy} = 4.93(10^6)$$

(b) Orthogonal Case (Case 2)

Areas 3 and 4 (MAT2 (3)(4)) analyses were as follows:

Analysis Case 2 consists of a 90-degree rotation of Case 1 layup and was run to permit the extrapolation of findings between the two orthogonal extremes. For this case the Table 6 (Col. A) directional properties were reversed to obtain the following: $E_{11} = 3.6(10^6)$, $E_{22} = 19.0(10^6)$, $G_{yy} = .65(10^6)$, $\mu_{12} = .0378$, and $\mu_{21} = .20$.

from which:

$$G_{11} = 3.63(10^6)$$

$$G_{22} = 19.144(10^6)$$

$$G_{12} = (.20)\ (3.6)(10^6)/.99244 = .725$$

$$G_{13} = G_{23} = 0$$

$$G_{33} = .65(10^6)$$

Area 2 (MAT2 (2)) analyses proceeded as follows:

By simply reversing the Case 1 modulus values, we have:

$$E_{11} = 14.74(10^6),\ E_{22} = 23.55(10^6)$$

$$G_{xy} = 4.92(10^6)$$

$$\mu_{21} = 0.2881 \text{ (from SQ5 reverse)}$$

From this then:

$$G_{11} = 15.54(10^6) \text{ and } G_{22} = 24.84(10^6)$$

$$Q_{12} = (0.288)(14.74) = 4.245(10^6)$$

$$G_{12} = Q_{12}/1-\mu_{12}\mu_{21} = 4.47(10^6)$$

$$G_{13} = G_{23} = 0$$

$$G_{33} = G_{xy} = 4.93(10^6)$$

(2) MAT2 Input Summary (Cases 1 and 2)

All of the G values generated for Cases 1 and 2 as input into the NASTRAN bulk data set is summarized in Table 7.

TABLE 7

"MAT2" SUMMARY CASES 1 AND 2

VARIABLE & COLUMN	MAT2 1-8	MID 9-16	G_{11} 17-24	G_{12} 25 -32	G_{13} 33-40	G_{22} 41-48	G_{23} 49-56	G_{33} 57-64	RHØ 65-72
ANALYSIS CASE NO.1	MAT2	2	24.84+6	4.47+6	-	15.54+6	-	4.93+6	.146
	MAT2	3	19.14+6	.72+6	-	3.63+6	-	.65+6	.056
	MAT2	4	19.14+6	.72+6	-	3.63+6	-	.65+6	.056
ANALYSIS CASE NO.2	MAT2	2	15.54+6	4 +6	-	24.84+6	-	4.93+6	.146
	MAT2	3	3.63+6	.72+6	-	19.14+6	-	.65+6	.056
	MAT2	4	3.63+6	.72+6	-	19.14+6	-	.65+6	.056

(3) MAT2 Input Summary (Cases 1 through 10)

Following the above procedure a complete derivation of all MAT2 input requirements was then made. The first step of this summary was to run all of the SQ5 runs required to derive the laminate properties for the 40/60 steel-to-composite section of the vane. Table 8 summarizes all of the values extracted from each of the SQ5 runs.

The next step was to directionally correct the Table 8 values by means of Equations 5a through 5g into a set of G values for each laminate noted in Table 8. The results of this conversion are noted in Table 9. The resulting Table 9 values were expanded to the orthogonal sets and all of the required Area 2 input values were derived for Cases 1 through 8, as noted in Table 10. Also contained within Tables 9 and 10 are the associated values for analysis Cases 9 and 10. Input for these cases will be discussed in the next section.

TABLE 8

SQ5 PROPERTIES FOR 40/60 STEEL COMPOSITE BOOT AREA, USING 5 DIFFERENT COMPOSITE INSERTS

PROP. \ LAYUP	HS-FIBER $[0_9, 90]_s$	HM-FIBER $(0_9, 90,)_s$	HS-FIBER $(\pm 45)_s$	SPEC.FIBER (± 45)	21 KSI AS-FIBER $(0_3, \pm 45, 90)_s$
E_x	23.55	25.73	14.10	14.31	19.44
E_y	14.74	15.03	14.10	14.31	15.88
G_{xy}	4.93	4.93	7.85	8.42	5.90
M_x	.288	.289	.429	.450	.316
* M_y	.180	.169	.429	.450	.258
$1-M_xM_y$	.948	.951	.816	.798	.918

(*Derived via Equation 3)

The next step in the MAT2 summarization is the definition of the G matrix for vane areas 3 and 4. This was done through the use of the base Equations 1 and 4. From these equations and data established in Table 6 the summarized results noted in Table 11 for areas 3 and 4 were obtained.

TABLE 9

"MAT2" INPUT G VALUE AND ASSOCIATED EQUATIONS (X 10^6)

LAYUP / PROP	HS-FIBER $[0_9, 90]s$	HM-FIBER $[0_9, 90]s$	HS-FIBER $[\pm 45]s$	SPEC-FIBER $[\pm 45]s$	21 KSI AS-FIBER $[0_3, \pm 45, 90]s$
G_{11}	24.84	27.05	17.28	17.93	21.18
G_{22}	15.54	15.80	17.28	17.93	17.30
G_{12}	4.47	4.57	7.41	8.07	5.46
G_{13}	0	0	0	0	0
G_{23}	0	0	0	0	0
G_{33}	4.93	4.93	7.85	8.42	5.90

$$G_{11} = \frac{E_y}{1-\mu_{12}\mu_{21}} \quad \text{(From Equation 4)} \qquad (5a)$$

$$\mu_x E_y = \mu_y E_x \text{ or } \mu_{12} E_{22} = \mu_{21} E_{11} \qquad (5b)$$

$$M_{21} = \frac{\mu_{12}\ E_{22}}{E_{11}} = \frac{\mu_x\ E_y}{E_x} \quad \text{(From Equation 3)} \qquad (5c)$$

$$G_{22} = \frac{E_y}{1-\mu_x M_y} \qquad (5d)$$

$$G_{12} = \frac{21\ E_{11}}{1-\mu_x\mu_y} = \frac{\mu_y E_x}{1-\mu_x\mu_y} \qquad (5e)$$

$$G_{13} = G_{23} = 0 \qquad (5f)$$

$$G_{33} = G_{xy} = \qquad (5g)$$

TABLE 10

SUMMARIZED MAT2 VALUES FOR VANE AREA NO. 2

COL. / CASE	1-8	9-16	G_{11} 17-24	G_{12} 25-32	G_{13} 33-40	G_{2} 41-48	G_{23} 49-56	G_{33} 57-64	RHØ 65-72
1	MAT2	2	24.84+6	4.47+6	-	15.54+6	-	4.93+6	.146
2	MAT2	2	15.54+6	4.47+6	-	24.84+6	-	4.93+6	.146
3	MAT2	2	17.28+6	7.41+6	-	17.28+6	-	7.85+6	.146
4	MAT2	2	27.05+6	4.57+6	-	15.80+6	-	4.93+6	.146
5	MAT2	2	15.80+6	4.57+6	-	27.05+6	-	4.93+6	.146
6	MAT2	2	17.93+6	8.07+6	-	17.93+6	-	8.42+6	.146
7	MAT2	2	21.18+6	5.46+6	-	17.30+6	-	5.90+6	.146
8	MAT2	2	17.30+6	5.46+6	-	21.18+6	-	5.90+6	.146
CHOP	MAT2	2	20.05+6	5.99+6	-	20.05+6	-	7.74+6	.146
BASE	MAT2	2	15.12+6	3.67+6	-	15.12+6	-	5.60+6	.152

TABLE 11

VANE AREAS NO. 3 AND NO. 4 "MAT2" DATA INPUT

CASE \ COL.	1-8	9-16	G_{11} 17-24	G_{12} 25-32	G_{13} 33-40	G_{22} 41-48	G_{23} 49-56	G_{33} 57-64	RHØ 65-72
1	MAT2	↑	19.14	.724	-	3.63	-	.65	.056
2	MAT2		3.63	.726	-	19.14	-	.65	.056
3	MAT2	(1)	6.53	5.23	-	6.53	-	5.52	.056
4	MAT2	E	22.88	1.077	-	4.15	-	.65	.056
5	MAT2	N	4.15	1.079	-	22.88	-	.65	.056
6	MAT2	O	3.45	2.86	-	3.45	-	6.46	.056
7	MAT2	N	12.98	1.970	-	6.53	-	2.27	.056
8	MAT2		6.53	1.980	-	12.98	-	2.27	.056
CHOP	MAT2		14.815	4.415	-	14.815	-	5.20	.056
BASE	MAT2	↓	3.797	1.063	-	3.797	-	1.367	.066

(1) - 3 or 4, depending on area

(a) Analysis Cases 9 and 10

As noted in Tables 10 and 11, values for two additional cases were tabulated. These involved the chopped-graphite case (Case 9) and MAT2 basepoint run (Case 10). Each of these cases could have been simplified to MAT1 NASTRAN input, but were MAT2 input. Case 9 was input this way for program input/output consistency. Case 10, however, was included for correlation to a NASTRAN run, using MAT1 data cards. For this correlation the MAT2 values (G_{11}, G_{12}, G_{13}, G_{22}, G_{23}, and G_{33}) were generated through the equations which effectively degenerated the MAT2 data to MAT1 data within NASTRAN. Correlation was excellent (less than 1% error) between the two runs, indicating a high level of confidence in the MAT2 input. The comparative results for the Case 10 correlation were noted back in Table 5. New-data Cases 9 and 10 input values for Tables 10 and 11 were derived through Equations 1 and 4 and the data contained in Table 6, whereby orthotropic properties were degenerated by setting $E_{11} = E_{22}$. The shear was computed simply by: $G_{xy} = E/2(1+\mu)$ with $\mu = \mu_{12} = \mu_{21}$.

(b) Analysis MAT2 Input Summary For Cases 1 Through 10

The final step in the MAT2 summarization was to combine all of the data from previous tables into a summary table for each of the 10 analysis cases. This combination is noted in Table 12 where all of the data is ordered and set up as to the actual input format required by NASTRAN.

2. PART II (AXLE AND BOOT ELIMINATION)

The second part of the analysis consisted of eliminating both vane axles and the end boots (Figure 4). These design changes (denoted as FDL-1 and FDL-2) were effected quite simply through property changes to those elements representing the axle or boot portions of the model.

TABLE 12

NASTRAN INPUT SUMMARY FOR ANALYSIS CASES NO. 1 THROUGH 10

VARIABLE & COLUMN	MAT2 1-8	MID 9-16	G11 17-24	G12 25-32	G13 33-40	G22 41-48	G23 49-56	G33 57-64	RHO 65-72
ANALYSIS	MAT2	2	24.84+6	4.47+6	-	15.54+6	-	4.93+6	.146
CASE	MAT2	3	19.14+6	.72+6	-	3.63+6	-	.65+6	.056
No. 1	MAT2	4	19.14+6	.72+6	-	3.63+6	-	.65+6	.056
ANALYSIS	MAT2	2	15.54+6	4.47+6	-	24.84+6	-	4.93+6	.146
CASE	MAT2	3	3.63+6	.73+6	-	19.14+6	-	.65+6	.056
No. 2	MAT2	4	3.63+6	.73+6	-	19.14+6	-	.65+6	.056
ANALYSIS	MAT2	2	17.28+6	7.41+6	-	17.28+6	-	7.85+6	.146
CASE	MAT2	3	6.53+6	5.23+6	-	6.53+6	-	5.52+6	.056
No. 3	MAT2	4	6.53+6	5.23+6	-	6.53+6	-	5.52+6	.056
ANALYSIS	MAT2	2	27.05+6	4.57+6	-	15.80+6	-	4.93+6	.146
CASE	MAT2	3	22.88+6	1.08+6	-	4.15+6	-	.65+6	.056
No. 4	MAT2	4	22.88+6	1.08+6	-	4.15+6	-	.65+6	.056
ANALYSIS	MAT2	2	15.80+6	4.57+6	-	27.05+6	-	4.93+6	.146
CASE	MAT2	3	4.15+6	1.08+6	-	22.88+6	-	.65+6	.056
No. 5	MAT2	4	4.15+6	1.08+6	-	22.88+6	-	.65+6	.056
ANALYSIS	MAT2	2	17.93+6	8.07+6	-	17.93+6	-	8.42+6	.146
CASE	MAT2	3	3.45+6	2.86+6	-	3.45+6	-	6.46+6	.056
No. 6	MAT2	4	3.45+6	2.86+6	-	3.45+6	-	6.46+6	.056
ANALYSIS	MAT2	2	21.18+6	5.46+6	-	17.30+6	-	5.90+6	.146
CASE	MAT2	3	12.98+6	1.97+6	-	6.53+6	-	2.27+6	.056
No. 7	MAT2	4	12.98+6	1.97+6	-	6.53+6	-	2.27+6	.056
ANALYSIS	MAT2	2	17.30+6	5.46+6	-	21.18+6	-	5.90+6	.146
CASE	MAT2	3	6.53+6	1.98+6	-	12.98+6	-	2.27+6	.056
No. 8	MAT2	4	6.53+6	1.98+6	-	12.98+6	-	2.27+6	.056
CHOPPED	MAT2	2	20.05+6	5.99+6	-	20.05+6	-	7.74+6	.146
GRAPHITE	MAT2	3	14.82+6	4.42+6	-	14.82+6	-	5.20+6	.056
CASE	MAT2	4	14.82+6	4.42+6	-	14.82+6	-	5.20+6	.056
BASELINE	MAT2	2	15.12+6	3.67+6	-	15.12+6	-	5.60+6	.152
CASE	MAT2	3	3.80+6	1.06+6	-	3.80+6	-	1.37+6	.066
	MAT2	4	3.80+6	1.06+6	-	3.80+6	-	1.37+6	.066

(For Boot Area PID = 2) 60% = composite 40% = steel)

a. Axle Removal (FDL-1)

Within the advanced composite (Part I) model the axles are represented by 7th and 8th (Areas 7 and 8, Figure 14) MAT items in the MAT data set. For these items, the modules and density properties were assigned insignificant values of 3.0 and .0001, respectively. This, in effect, yields a set of axles with no weight nor stiffness, thus eliminating them from the model.

b. Boot Removal (FDL-2)

Within the Part I model, the boots are represented by the 1st and 2nd (Areas 1 and 2, Figure 14) MAT items in the MAT data set. For boot removal, the properties for these areas were simply equated to those in areas 3 and 4, which resulted in a uniform vane of one material and no boots.

3. PART III (VANE THICKNESS VARIATIONS) FDL-2-.xt

The third portion of this study consisted of changing the thickness of the two most promising designs resulting from the parts II and III studies. Here again, the model change was quite simple because the "PQUAD2" data sets controlling the thickness valves in Areas 1 through 4 (Figure 14) were all that needed revision. The specific analysis consisted of reducing the thickness to 70%, 60%, 50%, and 40% of the basepoint thickness values carried in Parts I and II.

4. PARTS I, II, AND III SUMMARY

A complete summary of all revisions to the NASTRAN program required for the analysis is noted in Table 13. The data contained in this table was generated from the actual NASTRAN changes for each of the 22 computer runs comprising the analysis conducted in this report. Typically, the data supplied in Table 13 were the only changes made to the NASTRAN program noted in Appendix C.

TABLE 13

ACTUAL NASTRAN INPUT CHANGES

a. Analysis Cases 1 Through 10

```
TITLE=K.P.SCHWARTZ, ANALYSIS #1  ( 0 DEG. LAYERS=9, 90 DEG. LAYERS=1) HS
 MAT2     2       24.84+6  4.47+6           15.54+6           4.93+6 .146
 MAT2     3       19.14+6   .72+6            3.63+6            .65+6 .056
 MAT2     4       19.14+6   .72+6            3.63+6            .65+6 .055

TITLE=K.P.SCHWARTZ, ANALYSIS #2  ( 0 DEG. LAYERS=1, 90 DEG. LAYERS=9) HS
 MAT2     2       15.54+6  4.47+6           24.84+6           4.93+6 .146
 MAT2     3        3.63+6   .73+6           19.14+6            .65+6 .056
 MAT2     4        3.63+6   .73+6           19.14+6            .65+6 .056

TITLE=K.P.SCHWARTZ, ANALYSIS #3  ( ALTERNATING +45,-45 DEG. LAYERS  ) HS
 MAT2     2       17.28+6  7.41+6           17.28+6           7.85+6 .146
 MAT2     3        6.53+6  5.23+6            6.53+6           5.52+6 .055
 MAT2     4        6.53+6  5.23+6            6.53+6           5.52+6 .055

TITLE=K.P.SCHWARTZ, ANALYSIS #4  ( 0 DEG. LAYERS=9, 90 DEG. LAYERS=1) HM
 MAT2     2       27.05+6  4.57+6           15.80+6           4.93+6 .146
 MAT2     3       22.88+6  1.08+6            4.15+6            .65+6 .056
 MAT2     4       22.88+6  1.08+6            4.15+6            .65+6 .055

TITLE=K.P.SCHWARTZ, ANALYSIS #5  ( 0 DEG. LAYERS=1, 90 DEG. LAYERS=9) HM
 MAT2     2       15.80+6  4.57+6           27.05+6           4.93+6 .145
 MAT2     3        4.15+6  1.08+6           22.88+6            .65+6 .056
 MAT2     4        4.15+6  1.08+6           22.88+6            .65+6 .056

TITLE=K.P.SCHWARTZ, ANALYSIS #6  ( ALTERNATING +45,-45 DEG. LAYERS  ) HM
 MAT2     2       17.93+6  8.07+6           17.93+6           8.42+6 .146
 MAT2     3        3.45+6  2.86+6            3.45+6           6.46+6 .056
 MAT2     4        3.45+6  2.86+6            3.45+6           6.46+6 .056

TITLE=K.P.SCHWARTZ, ANALYSIS #7  ( 0 DEG.=3,+45,-45,90 DEG.  LAYERS ) AS
 MAT2     2       21.18+6  5.46+6           17.30+6           5.90+6 .146
 MAT2     3       12.98+6  1.97+6            6.53+6           2.27+6 .056
 MAT2     4       12.98+6  1.97+6            6.53+6           2.27+6 .056

TITLE=K.P.SCHWARTZ, ANALYSIS #8  (90 DEG.=3,+45,-45, 0 DEG.  LAYERS ) AS
 MAT2     2       17.30+6  5.46+6           21.18+6           5.90+6 .146
 MAT2     3        6.53+6  1.98+6           12.98+6           2.27+6 .056
 MAT2     4        6.53+6  1.98+6           12.98+6           2.27+6 .056

TITLE=K.P.SCHWARTZ, ANALYSIS #9  ( CHOPPED GRAPHITE MATERIAL)
 MAT2     2       20.05+6  5.99+6           20.05+6           7.74+6 .146
 MAT2     3       14.82+6  4.42+6           14.82+6           5.20+6 .055
 MAT2     4       14.82+6  4.42+6           14.82+6           5.20+6 .056

TITLE=K.P.SCHWARTZ, ANALYSIS #10 ( GRAPHITE COMPACT MATERIAL)
 MAT2     2       15.12+6  3.67+6           15.12+6           5.60+6 .152
 MAT2     3        3.80+6  1.06+6            3.80+6           1.37+6 .066
 MAT2     4        3.80+6  1.06+6            3.80+6           1.37+6 .066
```

TABLE 13 (CONT'D)
ACTUAL NASTRAN INPUT CHANGES
b. Analysis Cases 7A Through 7D

```
TITLE=K.P.SCHWARTZ, NO AXLES #7   ( 0 DEG.=3,+45,-45,90 DEG.  LAYERS ) AS
 MAT2    2       21.18+6  5.46+6          17.30+6            5.90+6 .146
 MAT2    3       12.98+6  1.97+6           6.53+6            2.27+6 .056
 MAT2    4       12.98+6  1.97+6           6.53+6            2.27+6 .056
MAT1            7   3.0E0             .3200   .0001
MAT1            8   3.0E0             .3200   .0001
```

```
TITLE=K.P.SCHWARTZ, NO BOOTS #7B ( 0 DEG.=3,+45,-45,90 DEG.  LAYERS ) AS
 MAT2    1       12.98+6  1.97+6           6.53+6            2.27+6 .056
 MAT2    2       12.98+6  1.97+6           6.53+6            2.27+6 .056
 MAT2    3       12.98+6  1.97+6           6.53+6            2.27+6 .056
 MAT2    4       12.98+6  1.97+6           6.53+6            2.27+6 .056
MAT1            7   3.0E0             .3200   .0001
MAT1            8   3.0E0             .3200   .0001
```

```
TITLE=K.P.SCHWARTZ, 70% SIZE #7C ( 0 DEG.=3,+45,-45,90 DEG.  LAYERS ) AS
PQUAD2          1       1   .2620
PQUAD2          2       2   .2620
PQUAD2          3       3   .2620
PQUAD2          4       4   .2620
 MAT2    1       12.98+6  1.97+6           6.53+6            2.27+6 .056
 MAT2    2       12.98+6  1.97+6           6.53+6            2.27+6 .056
 MAT2    3       12.98+6  1.97+6           6.53+6            2.27+6 .056
 MAT2    4       12.98+6  1.97+6           6.53+6            2.27+6 .056
MAT1            7   3.0E0             .3200   .0001
MAT1            8   3.0E0             .3200   .0001
```

```
TITLE=K.P.SCHWARTZ, 60% SIZE #7D ( 0 DEG.=3,+45,-45,90 DEG.  LAYERS ) AS
PQUAD2          1       1   .2240
PQUAD2          2       2   .2240
PQUAD2          3       3   .2240
PQUAD2          4       4   .224
 MAT2    1       12.98+6  1.97+6           6.53+6            2.27+6 .056
 MAT2    2       12.98+6  1.97+6           6.53+6            2.27+6 .056
 MAT2    3       12.98+6  1.97+6           6.53+6            2.27+6 .056
 MAT2    4       12.98+6  1.97+6           6.53+6            2.27+6 .056
MAT1            7   3.0E0             .3200   .0001
MAT1            8   3.0E0             .3200   .0001
```

c. Analysis Cases 7E and 7F

```
TITLE=K.P.SCHWARTZ, 50% SIZE #7E ( 0 DEG.=3,+45,-45,90 DEG.  LAYERS ) AS
PQUAD2          1       1   .1870
PQUAD2          2       2   .1870
PQUAD2          3       3   .1870
PQUAD2          4       4   .1870
 MAT2    1       12.98+6  1.97+6           6.53+6            2.27+6 .056
 MAT2    2       12.98+6  1.97+6           6.53+6            2.27+6 .056
 MAT2    3       12.98+6  1.97+6           6.53+6            2.27+6 .056
 MAT2    4       12.98+6  1.97+6           6.53+6            2.27+6 .056
MAT1            7   3.0E0             .3200   .0001
MAT1            8   3.0E0             .3200   .0001
```

```
TITLE=K.P.SCHWARTZ, 40% SIZE #7F ( 0 DEG.=3,+45,-45,90 DEG.  LAYERS ) AS
PQUAD2          1       1   .1500
PQUAD2          2       2   .1500
PQUAD2          3       3   .1500
PQUAD2          4       4   .1500
 MAT2    1       12.98+6  1.97+6           6.53+6            2.27+6 .056
 MAT2    2       12.98+6  1.97+6           6.53+6            2.27+6 .056
 MAT2    3       12.98+6  1.97+6           6.53+6            2.27+6 .056
 MAT2    4       12.98+6  1.97+6           6.53+6            2.27+6 .056
MAT1            7   3.0E0             .3200   .0001
MAT1            8   3.0E0             .3200   .0001
```

TABLE 13 (CONT'D)
ACTUAL NASTRAN INPUT CHANGES
d. Analysis Cases 9A Through 9D

```
TITLE=K.P.SCHWARTZ, NO AXLES #9  ( CHOPPED GRAPHITE MATERIAL)
 MAT2    2        20.05+6  5.99+6          20.05+6               7.74+6 .146
 MAT2    3        14.82+6  4.42+6          14.82+6               5.20+6 .056
 MAT2    4        14.82+6  4.42+6          14.82+6               5.20+6 .056
MAT1             7    3.0E0            .3200    .0001
MAT1             8    3.0E0            .3200    .0001
```

```
TITLE=K.P.SCHWARTZ, NO BOOTS #9B ( CHOPPED GRAPHITE MATERIAL)
 MAT2    1        14.82+6  4.42+6          14.82+6               5.20+6 .056
 MAT2    2        14.82+6  4.42+6          14.82+6               5.20+6 .056
 MAT2    3        14.82+6  4.42+6          14.82+6               5.20+6 .056
 MAT2    4        14.82+6  4.42+6          14.82+6               5.20+6 .056
MAT1             7    3.0E0            .3200    .0001
MAT1             8    3.0E0            .3200    .0001
```

```
TITLE=K.P.SCHWARTZ, 70% SIZE #9C ( CHOPPED GRAPHITE MATERIAL)
PQUAD2           1          1    .2620
PQUAD2           2          2    .2620
PQUAD2           3          3    .2620
PQUAD2           4          4    .2620
 MAT2    1        14.82+6  4.42+6          14.82+6               5.20+6 .056
 MAT2    2        14.82+6  4.42+6          14.82+6               5.20+6 .056
 MAT2    3        14.82+6  4.42+6          14.82+6               5.20+6 .056
 MAT2    4        14.82+6  4.42+6          14.82+6               5.20+6 .056
MAT1             7    3.0E0            .3200    .0001
MAT1             8    3.0E0            .3200    .0001
```

```
TITLE=K.P.SCHWARTZ, 60% SIZE #9D ( CHOPPED GRAPHITE MATERIAL)
PQUAD2           1          1    .2240
PQUAD2           2          2    .2240
PQUAD2           3          3    .2240
PQUAD2           4          4    .224
 MAT2    1        14.82+6  4.42+6          14.82+6               5.20+6 .056
 MAT2    2        14.82+6  4.42+6          14.82+6               5.20+6 .056
 MAT2    3        14.82+6  4.42+6          14.82+6               5.20+6 .056
 MAT2    4        14.82+6  4.42+6          14.82+6               5.20+6 .056
MAT1             7    3.0E0            .3200    .0001
MAT1             8    3.0E0            .3200    .0001
```

e. Analysis Cases 9E and 9F

```
TITLE=K.P.SCHWARTZ, 50% SIZE #9E ( CHOPPED GRAPHITE MATERIAL)
PQUAD2           1          1    .1870
PQUAD2           2          2    .1870
PQUAD2           3          3    .1870
PQUAD2           4          4    .1870
 MAT2    1        14.82+6  4.42+6          14.82+6               5.20+6 .056
 MAT2    2        14.82+6  4.42+6          14.82+6               5.20+6 .056
 MAT2    3        14.82+6  4.42+6          14.82+6               5.20+6 .056
 MAT2    4        14.82+6  4.42+6          14.82+6               5.20+6 .056
MAT1             7    3.0E0            .3200    .0001
MAT1             8    3.0E0            .3200    .0001
```

```
TITLE=K.P.SCHWARTZ, 40% SIZE #9F ( CHOPPED GRAPHITE MATERIAL)
PQUAD2           1          1    .1500
PQUAD2           2          2    .1500
PQUAD2           3          3    .1500
PQUAD2           4          4    .1500
 MAT2    1        14.82+6  4.42+6          14.82+6               5.20+6 .056
 MAT2    2        14.82+6  4.42+6          14.82+6               5.20+6 .056
 MAT2    3        14.82+6  4.42+6          14.82+6               5.20+6 .056
 MAT2    4        14.82+6  4.42+6          14.82+6               5.20+6 .056
MAT1             7    3.0E0            .3200    .0001
MAT1             8    3.0E0            .3200    .0001
```

SECTION V

VANE ANALYSIS

The overall analysis consists of a total of 22 NASTRAN runs summarized in Table 14. The first of these runs consists of a single baseline run (Case 10, Table 14) representing the current ROVAC vane. The next series of runs consists of nine surveys (Cases 1 through 9, Table 14) investigating several different layups and fiber types with which a ROVAC vane could be constructed. Two of the nine cases were selected as the most promising for further analysis.

The specific cases selected for further study were Cases 7 and 9, primarily due to the minimal tip deflections experienced with these two designs. The additional analysis consisted of first removing the axles from the vane (subcase A) and secondly removing both the axles and boots from the vane (subcase B). These cases are referred to as design types FDL-1 and FDL-2, respectively, and are noted as test cases 7A, 7B, 9A, and 9B in Table 14.

Following the axle and boot removal, subcases C, D, E, and F were run on FDL-2 design and consisted of thinning the FDL-2 design to .7, .6, .5, and .4, of the original thickness. These cases are referred to by their thickness value (t) added to the design type designation. The actual analysis cases are noted as test cases 7C through 7F and 9E through 9F. An additional designation (CG) has also been added to the design type to distinguish the chopped-graphite material from the layup type structures of Case 7.

Within the analysis, the NASTRAN case control program (Appendix C, Pg 120) was written to yield node point displacements, load vectors, single point constraint forces, quadrilateral and bar element forces, and quadrilateral and bar element stresses. In addition to this tabular output, two plots consisting of single and superimposed deflected shapes were also programmed.

TABLE 14

SUMMARY OF ALL CASES AND DESIGN VARIATIONS ANALYZED

TEST CASE	CDC RUN DESIGNATION	LAYUP STRUCTURE	FIBER TYPE	DESIGN TYPE
1	W71/00QA	9(0°), 1(90°)	HS	ROVAC
2	W72/00GN	1(0°), 9(90°)	HS	ROVAC
3	W73/0087	+45°, -45°	HS	ROVAC
4	W74/00ØB	9(0°), 1(90°)	HM	ROVAC
5	W75/00Q7	1(0°), 9(90°)	HM	ROVAC
6	W76/00HI	+45°, -45°	Special	ROVAC
7	W77/00HB	3(0°), +45 -45, 1(90°)	AS	ROVAC
8	W78/00DE	3(90°), +45 -45, 1(0°)	AS	ROVAC
9	W79/00DX	CHOPPED GRAPHITE	-	ROVAC
10	W70/00GL	COMPACT GRAPHITE	-	ROVAC
7A	W7A/0078	Ref.Case 7	AS	FDL-1

TEST CASE	CDC RUN DESIG.	LAYUP STRUCTURE	FIBER TYPE	DESIGN TYPE
7B	W7C/008L	Ref. Case 7	AS	FDL-2
7C	W7E/004P	Ref. Case 7	AS	FDL-2-.7t
7D	W7G/008S	Ref. Case 7	AS	FLD-2-.6t
7E	W7I/AEK3	Ref. Case 7	AS	FDL-2-.5t
7F	W7K/AEKV	Ref. Case 7	AS	FDL-2-.4t
9A	W7B/006S	Ref. Case 9	-	FDL-1 (CG)
9B	W7D/00D9	Ref. Case 9	-	FDL-2 (CG)
9C	W7F/004Ø	Ref. Case 9	-	FDL-2-7t (CG)
9D	W7H/008R	Ref. Case 9	-	FDL-2-.6t (CG)
9E	W7J/AEK1	Ref. Case 9	-	FDL-2-.5t (CG)
9F	W7L/AELD	Ref. Case 9	-	FDL-2-.4t (CG)

FDL-1 = axles removed from basic ROVAC design.
FDL-2 = axles and boots removed from basic ROVAC design.
t = basic ROVAC vane thickness.

1. PART I ANALYSIS AND DISCUSSION

Actual data extracted from the NASTRAN output was limited to six primary deflections, the ten highest stresses in the vane itself, and the resulting bearing loads and the vane weight. The six primary deflections of interest are noted in Figure 15. Actual quantitative deflection values (Figure 15) for Cases 1 through 10 are included in Table 15, along with vane weight and resulting bearing loads. For this analysis and the following Part II and III studies, deflection, load, and weight data were extracted as follows:

Deflection: A = T1 or X deflection @ Node point 1
B = T2 or Y deflection @ Node point 1
C = T2 or Y deflection @ Node point 28
D = T2 or Y deflection @ Node point 309
E = T2 or Y deflection @ Node point 476

Bearing Load: Summation of T2 SPC forces at node points 477, 478, 479, and 480.

Vane Weight: 2X mass noted in grid point weight generator.

Element and
Nodal Locations: Refer to pages 101, 102, 103, Appendix B.

The resultant stress data is noted in Tables 16a and 16b. This tabulation notes the ten highest stresses occurring in the vane. All of the stresses noted in Table 16 occur in either the vane boot region or the vane closeout structure. In view of this fact, Tables 17a and 17b are also included, in which is related detailed stress data as restricted to the composite portion of the vane only.

For the most part, the data presented in Tables 15, 16, and 17 is self-explanatory. Tip deflection for cases 1 through 9 ranged from .93 mils to 3.74 mils, as compared to the basepoint ROVAC value of 2.91 mils. It may be well to note that this 2.91 basepoint value compares favorably with an estimated 3.0 value assessed in an AFFDL

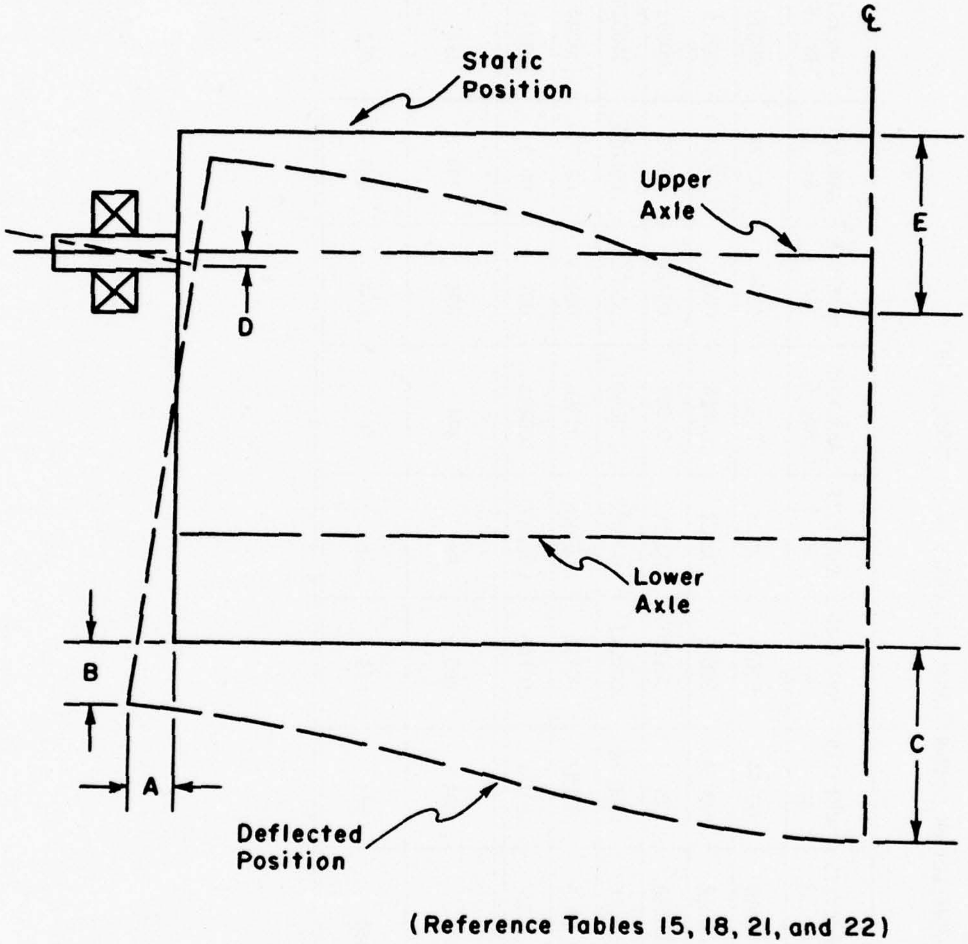

Figure 15. Tabulated Deflections, Positions A Through E

TABLE 15

LOAD/DEFLECTION SUMMARY (ANALYSIS CASES NO. 1 THROUGH 10)

FIG. DEFLECTION VALUE	BASELINE No. 10	ANALYSIS No. 1	ANALYSIS No. 2	ANALYSIS No. 3	ANALYSIS No. 4	ANALYSIS No. 5	ANALYSIS No. 6	ANALYSIS No. 7	ANALYSIS No. 8	ANALYSIS No. 9
A (INCHES)	.00134	.00029	.00116	.00144	.00024	.00105	.00224	.0004	.00074	.00037
B (INCHES)	.000256	.00019	.00022	.00024	.00019	.00021	.00026	.0002	.0002	.00019
C (INCHES)	.00291	.00193	.00324	.00221	.00185	.00310	.00309	.00120	.00170	.00093
D (INCHES)	.0000707	.000048	.000063	.000068	.000047	.000062	.000080	.000050	.000056	.000029
E (INCHES)	.00298	.00193	.00326	.00247	.00185	.00310	.00356	.00123	.0017	.00094
C-B (INCHES)	.00157	.00174	.00302	.00197	.00166	.00289	.00283	.001	.0015	.00074
(LBS.) BEARING LOAD	975	895	894	894	895	894	894	894	894	894
VANE WEIGHT (LBS)	.942	.864	.864	.864	.864	.864	.864	.864	.864	.864

TABLE 16

MAXIMUM PRINCIPAL STRESS SUMMARY REFLECTING THE TOP TEN STRESS VALUES

a. Analysis Cases 1 Through 4 and Baseline

BASELINE		ANALYSIS No. 1		ANALYSIS No. 2		ANALYSIS No. 3		ANALYSIS No. 4	
ELEMENT	STRESS	ELEMENT	STRESS	ELEMENT	STRESS	ELEMENT	STRESS	ELEMENT	STRESS
163	3035	163	2465	246	3031	163	2861	163	2426
190	4679	190	4158	190	3921	190	4023	190	4093
191	3908	191	3553	191	3254	191	3223	191	3501
217	3887	215	3773	217	3397	217	3115	217	3728
218	3906	218	3670	218	3351	218	3118	218	3626
244	4931	244	5111	244	4402	244	3805	244	5070
245	4838	245	4275	245	4206	245	3937	245	4219
271	8608	271	6241	271	7697	271	7649	271	6086
272	7004	272	4468	272	6212	272	6405	272	4334
273	3160	164	2594	273	3110	273	3240	164	2554

Stress in PSI

b. Cases 5 Through 9

ANALYSIS No. 5		ANALYSIS No. 6		ANALYSIS No. 7		ANALYSIS No. 8		ANALYSIS No. 9	
ELEMENT	STRESS	ELEMENT	STRESS	ELEMENT	STRESS	ELEMENT	STRESS	ELEMENT	STRESS
246	3152	163	2975	163	2462	163	2395	244	4572
190	3863	190	3969	190	3917	190	3800	190	3571
191	3208	191	3101	191	3346	191	3208	191	3038
217	3399	217	2821	217	3504	217	3348	217	3240
218	3336	218	2870	218	3492	218	3349	218	3249
244	4458	244	3209	245	4204	245	4147	245	4027
245	4182	245	3772	246	2515	246	2749	246	2668
271	7564	271	8269	271	6436	271	6985	271	6259
272	6039	272	7356	272	4780	272	5435	272	4688
273	3122	273	3670	164	2480	273	2827	273	2617

Stress in PSI

TABLE 17

COMPOSITE REGION STRESS SUMMARY

a. Analysis Cases 1 Through 10

	ELEMENT	NORMAL X	NORMAL Y	SHEAR XY	MAJOR PRINCIPAL	ANGLE α	MAX. SHEAR
BASELINE (No. 10)	*						
	27	1875	13.1	-4.5	1875	-.14	931
	81	1586	44.8	-15.4	1586	-.57	770
	**						
	227	450	97.0	745	1039	-38.34	765
	254	414	22.7	704	949	-37.22	730
	281	321	-74.2	-569	726	-35.43	602
	308	240	-111.7	-411	511	-33.42	447
ANALYSIS No. 1	*						
	27	2313	8.95	5.28	2313	-.13	1152
	81	1558	35.4	14.2	1558	-.54	761
	**						
	227	435	0	-556	815	-34.34	597
	254	363	-67.5	-507	700	-33.49	552
	281	178	-131	-398	451	-34.36	427
	308	-115	-113	-325	211	-45.09	325
ANALYSIS No. 2	*						
	27	1684	10.63	3.8	1684	-.13	837
	81	1366	39.32	-13.70	1366	-.59	663
	**						
	227	367	-137	-559	728	-32.84	613
	254	306	-352	-511	585	-28.60	608
	281	203	-642	-415	373	-22.23	592
	308	124	-486	-306	251	-22.54	432
ANALYSIS No. 3	*						
	27	1386	18.88	-4.9	1386	-.21	683
	81	1225	43.81	-14.63	1226	-.71	591
	**						
	227	439	299	-730	1103	-42.25	734
	254	443	282	-726	1093	-41.84	730
	281	386	211	-631	936	-41.04	637
	308	322	152	-494	738	-40.12	502
ANALYSIS No. 4	*						
	27	2373	8.82	-5.52	2373	-.14	1182
	81	1548	34.78	-14.45	1549	-.55	756
	**						
	227	439	9.07	-553	817	-34.35	593
	254	369	-63.8	-505	702	-33.38	549
	281	170	-134	-397	443	-34.55	425
	308	-147	-108	-330	203	-46.67	331

*The two highest stress values.
**Bearing support region stress.

TABLE 17 (Cont'd)

COMPOSITE REGION STRESS SUMMARY

b. Analysis Cases 5 Through 9

	ELEMENT	NORMAL X	NORMAL Y	SHEAR XY	MAJOR PRINCIPAL	ANGLE α	MAX. SHEAR
ANALYSIS No. 5	* 27	1741	10.84	-3.86	1741	-.13	865
	81	1402	39.48	-13.56	1402	-.57	681
	** 227	376	-175	-556	721	-31.81	621
	254	312	-412	-507	572	-27.22	623
	281	199	-722	-411	356	-20.87	617
	308	110	-524	-304	231	-21.89	438
ANALYSIS No. 6	*						
	27	1008	21.54	6.95	1008	-.404	493
	81	902	40.74	19.8	903	1.31	431
	**						
	227	294	230	-680	944	-43.63	681
	254	325	246	-705	992	-43.40	706
	281	315	217	-639	908	-42.81	641
	308	315	195	-579	837	-42.06	582
ANALYSIS No. 7	*						
	27	2007	10.36	-3.82	2007	-.11	998
	81	1637	39.14	-12.14	1637	-.44	799
	**						
	227	512	87.4	-674	1007	-36.25	706
	254	478	9.04	-611	899	-34.5	655
	281	349	-66.4	-474	659	-33.18	518
	308	133	-63.5	-324	374	-36.6	339
ANALYSIS No. 8	*						
	27	1818	11.1	-3.52	1818	-.11	903
	81	1529	40.5	-11.93	1529	-.46	744
	**						
	227	480	102	-683	1001	-37.28	709
	254	449	-17	-621	880	-34.71	664
	281	347	-146	-485	645	-31.54	545
	308	213	-150	-315	396	-30.03	364
ANALYSIS No. 9	*						
	27	1980	11.23	-3.54	1980	-.10	984
	81	1665	40.50	-11.36	1665	-.40	812
	**						
	227	579	239	-730	1160	-38.44	750
	254	549	139	-653	1029	-36.30	685
	281	415	40	-501	762	-34.73	534
	308	182	20	-316	427	-37.77	326

*The two highest stress values.
**Bearing support region stress.

ROVAC test effort. In general, stress for all of the design cases 1 through 9 were below that of the basepoint case. Since the composite designs of interest are far superior to the basepoint design, from a structural point of view, no further study was made relative to the resultant stresses. As noted in Table 15, vane weight was reduced from .942 lbs to .864 lbs. Due to this reduced mass, not only were the stresses reduced but the bearing load at the axle support was reduced from 975 lbs to 895 lbs.

Based primarily on the maximum tip deflection (value C, Table 15), designs from Cases 7 and 9 were selected for further study. Specifically for these cases, tip deflections were reduced from 2.91 miles to 1.20 and .93 mils. One secondary point to note is that the movement toward the compressor end plate (A, Figure 15) was also reduced by over 60%. This could very well contribute to a quieter and cooler running system due to reduced end plate forces.

Deflected shapes for all of the analysis cases (Parts I, II, and III) are included in Appendix D. These plots include the deflected shape superimposed on the original static shape. It should be noted that Appendix D figures cannot be compared to each other because NASTRAN plotting equates the maximum deflection to a specific value.

2. PART II ANALYSIS AND DISCUSSION

For the second analysis, the primary items of interest are the same as for the previous case. The overall bearing load, vane weight, and deflection summary data are noted in Table 18. Changing regions of maximum stress can be noted in Table 19 and quantitative stress data is included in Table 20. Again, element and nodal locations can be obtained by referring to Appendix B (Pages 101, 102, 103). All deflection, loads, and weight parameters are the same as in Part I.

The data has again been tabulated in a very self-explanatory manner. Tip deflections tended to increase about 14% for the FDL-1 (no axle) design. For the FDL-2 (no axle, no boot) design, additional tip deflection

TABLE 18

LOAD/DEFLECTION CHANGES DUE TO VANE REDESIGN

FIG. DEFLECTION VALUE	ANALYSIS No. 7	ANALYSIS No. 7A AXLES REMOVED	ANALYSIS No. 7B AXLES & BOOTS REMOVED	ANALYSIS No. 9	ANALYSIS No. 9A AXLES REMOVED	ANALYSIS No. 9B AXLES & BOOTS REMOVED
A	.00041	.00043	.0004	.00037	.00039	.00037
B	.0002	.00035	.00043	.00019	.00034	.00031
C	.00120	.00140	.00145	.00093	.00111	.00106
D	.00005	.0002	.00018	.000029	.00022	.00017
E	.00123	.0014	.0015	.00094	.00112	.00106
C-B	.001	.00105	.00102	.00074	.00077	.00075
BEARING LOAD (lbs)	894	801	626	894	801	626
VANE WEIGHT (lbs)	.864	.772	.608	.864	.772	.608

TABLE 19

ELEMENT NUMBERS DENOTING THE TEN HIGHEST MAXIMUM PRINCIPAL STRESS VALUES FOR EACH ANALYSIS CASE

No. 7	No. 7A	No. 7B	No.7C, 7D 7E, 7F	No. 9	No. 9A	No. 9B	No.9C, 9D	No.9E, 9F
		24	24					
		25	25					25
		26	26			26	26	26
		27	27			27	27	27
163	163				163			
164	164				164			
190	190	190	190	190	190	190	190	190
191	191	191	191	191	191	191	191	191
217	217	217	217	217	217	217	217	217
218	218	218	218	218	218	218	218	218
	219				219	219	219	219
	244	244	244	244	244	244	244	244
245	245	245	245	245	245	245	245	245
246	245			246	246	246	246	
271				271				
272				272				
				273				

TABLE 20

MAXIMUM PRINCIPAL STRESS SUMMARY FOR VANE REDESIGN
(INCLUDES ALL TABLE ELEMENTS)

ELEMENT \ ANALYSIS	No. 7	No. 7A	No. 7B	No. 9	No. 9A	No. 9B
24	1900	2000	1866	1879	1973	1851
25	1954	2054	1921	1930	2023	1899
26	1989	2088	1957	1963	2055	1931
27	2007	2106	1975	1980	2071	1947
163	2462	2540	1372	2568	2331	1307
164	2480	2580	1320	2237	2326	1307
190	3917	4165	2659	3571	3793	3034
191	3346	3566	1946	3038	3250	3962
217	3504	4182	1978	3240	3904	2262
218	3492	3886	1893	3249	3677	2198
219	2183	2464	1753	2244	2564	2022
244	4810	6175	2425	4572	5965	3277
245	4204	4081	1994	4027	4010	2462
246	2515	2441	2048	2668	2597	2048
271	6436	2122	1455	6259	2085	1582
272	4780	1739	1360	4688	1784	1460
273	2404	1424	1260	2617	1493	1327

Stress Values in PSI

changes were insignificant. No appreciable change was noted over the already improved lateral movement toward the compressor end plates. In general, no appreciable changes occurred to overall deflections in either the FDL-1 and FDL-2 cases.

In removing the vane axles and boots, vane weights were reduced further to .772 and .608 lbs, thereby substantially improving the bearing load properties. In addition to the bearing load improvements, maximum principal stresses were also reduced for the most part by almost 50% for the FDL-2 case. For the FDL-1 case, a 5 to 10% increase in stress values was noted.

In summary, it can be said that removing the axles, or axles and boots, does little to degrade the basic advanced composite approach. Improvements, however, are substantial in the area of load and stress reduction, particularly for the FDL-2 case. Based on these factors, the FDL-2 design was selected for further analysis in the Part III section of this study.

3. PART III ANALYSIS

The Part III analysis consisted of defining the effects of varying thickness on the FDL-2 design selected in the previous section. Overall deflection results for this analysis are included in Table 21 (FDL-2) and Table 22 (FDL-2(CG)). Stress data is tabulated in Tables 23 and 24 for the same respective designs. The primary item to note from this analysis is that although the amount of structure is reduced substantially, the effects upon vane stresses are only minor. In addition, with the decreased structure, the resultant deflections of interest were actually improved upon slightly. The prime improvement, however, was in the area of vane-bearing loads, where values ranged from 626 lbs down to 328 lbs for a vane of 40% of the original thickness.

TABLE 21

LOAD/DEFLECTION CHANGES DUE TO VANE RESIZING (MATERIAL = 0 Deg. = 3, +45, -45, 90 Deg.) AS Type

FIG. DEFLECTION VALUE	ANAL/7B t=100%	ANAL/7C t=70%	ANAL/7D t=60%	ANAL/7E t=50%	ANAL/7F t=40%
A	.00040	.00040	.00040	.00040	.00040
B	.00043	.00038	.00036	.00035	.00033
C	.00145	.00139	.00137	.00134	.00132
D	.00018	.000145	.000131	.000117	.000103
E	.0015	.0014	.00138	.00136	.00133
C-B	.00102	.00102	.00101	.00099	.00099
BEARING LOAD (lbs)	626	477	428	379	328
VANE WEIGHT (lbs)	.608	.465	.417	.370	.323

TABLE 22

LOAD/DEFLECTION CHANGES DUE TO VANE RESIZING (MATERIAL = CHOPPED GRAPHITE)

DEFLECTION VALUE	ANAL/9B t=100%	ANAL/9C t=70%	ANAL/9D t=60%	ANAL/9E t=50%	ANAL/9F t=40%
A	.00037	.00037	.00036	.00036	.00036
B	.00031	.00026	.00024	.00023	.00021
C	.00106	.00100	.00097	.00095	.00093
D	.00017	.00017	.00012	.00011	.00010
E	.00106	.00100	.00099	.00096	.00094
C-B	.00075	.00074	.00073	.00072	.00072
BEARING LOAD (lbs)	626	477	428	379	328
VANE WEIGHT (lbs)	.608	.465	.417	.370	.323

TABLE 23

MAXIMUM PRINCIPAL STRESS SUMMARY FOR CHANGES DUE TO VANE RESIZING
(TEN HIGHEST VALUES) (MATERIAL = 0 DEG. = 3, +45, -45, 90 DEG.)

ANALYSIS / ELEMENT	No. 7B	No. 7C	No. 7D	No. 7E	No. 7F
24	1866	1856	1850	1844	1835
25	1921	1910	1905	1898	1890
26	1957	1946	1940	1933	1924
27	1975	1963	1957	1951	1942
190	2659	2780	2826	2874	2922
191	1946	1991	2007	2025	2042
217	1978	1940	1923	1901	1876
218	1893	1846	1825	1800	1768
244	2425	2213	2130	2040	1938
245	1994	1870	1819	1762	1697

TABLE 24

MAXIMUM PRINCIPAL STRESS SUMMARY FOR CHANGES DUE TO VANE RESIZING
(TEN HIGHEST VALUES) (MATERIAL = CHOPPED GRAPHITE)

ANALYSIS / ELEMENT	No. 9B	No. 9C	No. 9D	No. 9E	No. 9F
25	—	—	—	1874	1865
26	1931	1919	1913	1906	1896
27	1947	1935	1929	1921	1912
190	3034	2588	2651	2720	2797
191	3962	2009	2030	2053	2078
217	2262	2199	2171	2140	2100
218	2198	2129	2097	2060	2012
219	2022	1962	1934	1900	1858
244	3277	2954	2820	2671	2501
245	2462	2296	2224	2142	2047
246	2048	1949	1905	1854	1792

The primary factor to be derived from this analysis is that for this particular design an optimum design would be the thinnest vane possible. Obviously other factors come into play such as manufacturing limitations and out-of-plane considerations. Typically, these considerations would include vane bending along with the complex aspects of modeling the structure with 3-dimensional isoparametric elements.

SECTION VI
CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

The results of the programs and analysis conducted within this program has led to the following observations or conclusions:

1. For the specific design considered within the analysis (Figure 4), the existing carbon compact type material can be improved upon substantially through the use of advanced composites. These improvements can further lead to more permissive design variation for the assembly and retention of materials into a ROVAC vane structure.

2. Through the use of the advanced vane materials and structural design changes analyzed in this program, total weights and operational bearing loads were reduced by 35%. In addition, the use of advanced composites allows for a design optimization toward the thinnest structure possible from either a manufacturing or operational point of view. Specifically the analysis considered vane sizes down to 40% of original size. For the reduced thickness cases, the vane was structurally sound (in the analysis plane) and total weights and operational bearing loads were reduced by 66%. Both the 35% and 66% reductions can also be accomplished while concurrently reducing the peak vane stresses by 30% to 60%.

3. The primary objectives of the study were to reduce the amount of tip and edge deflections occurring within the vane structure. Based on the results of this study it was concluded that deflections can be significantly improved through materials and/or design variations. Within the analysis, the most significant changes occurred from the composite materials substitution. Out of the nine materials variations considered within the analysis, the two best showed tip-deflection reductions of 68% and 59%, and concurrent edge-deflection reductions of 72% and 70%, respectively. The removal of vane axles and retention boots increased

the improved deflections by approximately 20%. These increases are only minor, however, since the original materials changes would still result in 62% and 50% improvements. The effects of reducing the vane thickness were generally positive, in that due to the decrease in inertia effects, deflections actually decreased even though the structure was thinned down substantially. Actual values were only minor, however, with a maximum 9% improvement being noted in the 0.4t case.

2. RECOMMENDATIONS

Based on the results of this program, it becomes evident that further study, analysis, and testing is required to fully optimize an advanced vane configuration. In this regard, the following considerations or recommendations are offered:

a. Materials Consideration

Based on initial ground rules, the analysis discussed in this report was restricted to advanced graphite composites. These types of materials have several basic disadvantages, consisting of high friction, abrasiveness, cost, and potential corrosion inducements. In addition, from the analysis, it was noted that the primary advantages of strength were not being fully exploited. By sacrificing strength and perhaps some stiffness, the associated materials disadvantages might be offset through alternate materials choices. Alternate materials choices offering improvements in these areas include Nomex and Kevlar, both of which could readily be incorporated into a ROVAC vane structure as either a compression-molded or laid-up structure. Both materials would eliminate corrosion and cost problems at the price of reduced but, most probably, adequate strength. In addition, these materials offer further improvements in the area of weight and friction. By further reducing the strength requirement, substantial improvements could be obtained (relative to cost and friction) through the use of fiberglass and/or powdered additives to the base resin system of the vane structure. This friction improvement may contribute to the reduction of internal heat generation within the ROVAC machine.

Based upon the previous discussion, four very important recommendations can be offered.

1. A preliminary structural analysis should be conducted defining the penalties and payoff for various alternate materials. Materials to be considered should include Nomex, Kevlar, fiberglass, and woven Teflon fabrics. In addition, resin system additives and supplements should also be considered within the analysis.

2. It is recommended that the analysis discussed above be conducted by simply varying the MAT2 properties of the NASTRAN program contained in Appendix C of this report.

3. For the recommended analysis, physical properties of some recommended materials may have to be generated. It is recommended that a materials test and evaluation program be initiated to define friction, wear, strength, and deflection properties for potential ROVAC vane materials for which no current data exists.

4. Many similar or even identical materials may be considered in a current FEM advanced composite bearing effort. It is recommended that coordination be maintained, with these efforts as they may prove invaluable in the selection of an advanced composite ROVAC vane material.

b. Analysis Verification

Although the reported analysis agrees with ROVAC deflection and loads data, it is recommended that a correlation test program be accomplished which would demonstrate the complete validity of the AVM and NASTRAN models generated in this report. The correlation program would not have to be elaborate and could simply consist of a representative static loading on a baseline ROVAC vane noting overall deflections and several selected strain values.

c. Design Variations

All of the designs considered within this study were restricted to the existing ROVAC design (Figure 4). For this design, geometric variables were constrained to values which may not necessarily be an optimum from a materials/structural relationship point of view. It is therefore recommended that geometric variations from Figure 4 be analyzed for more optimized materials selection. These optimums could then be compared to optimums from an air-cycle machine point of view and trade studies initiated for a fully optimum approach. These design runs could be very easily accomplished through the use of the AVM program developed in this report. In addition to the geometric changes, the AVM program also can rotate the materials axis to any value in four distinct areas. Applications of this capability may lead to still further design improvements.

d. Refined Analysis

All of the design changes studied in Section V assumed that some form of bearing support pin could be structurally integrated into the advanced composite region. Currently, several approaches exist for accomplishing this but all would require modification in areas of maximum stress. In view of this fact, it is recommended that these areas be refined, and the actual attachment method be modeled to determine the best method for bearing-load transition into the vane structure. Here again, the AVM program could be applied so that it possesses the capability to readily refine any area within the vane structure.

e. Margin of Safety (MOS) Study (Recommendation)

Although the stress levels noted in this report appear low, an MOS analysis should be conducted to pinpoint relative vane strength. This analysis would then enable realistic projections to be made relative to the degree of strength reductions permissible for the advanced materials previously recommended.

APPENDIX A

PROGRAM VANE LISTING IN AVM FORTRAN CODE

APPENDIX A

PROGRAM VANE LISTING IN AVM FORTRAN CODE

```
W7XKS,STANY,T1C.     D760133,SCHWARTZ,53011
FTN.
LGO.
REWIND,TAPE7.
COPYSBF,TAPE7,OUTPUT.
REWIND,TAPE7.
COPYBF,TAPE7,PUNCH.
EXIT,S.
      PROGRAM VANE (INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT,TAPE7)
C
C     THIS PROGRAM READS X AND Y DATA FROM CARDS AND CONSTRUCTS
C     A GRID FOR OUTPUT IN NASTRAN FORMAT
C
      COMMON /VANX/X(700),Y(700),XP(5),XTH(5),NP,TH(4)
      COMMON/DUMBAR/XROD1,YROD1,YROD2,NROD,NG1,NG2,ITOT,NR1,NR2
C
C     READ CARD INPUT
      CALL READIN
C
C     CALCULATE X-Y GRID AND PRINT GRID CARDS
      CALL GRID
C
C     CALCULATE AND PRINT VALUES FOR CQUAD2 CARDS
      CALL CQUAD2
C
C     CALCULATE CBAR VALUES
      IF (NROD.NE.0) CALL CBAR
C
C     CALCULATE SINGLE POINT CONSTRAINTS
      CALL SPC
C
C     CALCULATE MATERIAL AND PROPERTY DATA
      CALL CALCIN
C
      ENDFILE 7
      STOP
      END
      SUBROUTINE READIN
C
C     READIN READS THE FOLLOWING VALUES--
C
C     CARD 1, COL 1-5 - NPX - NO. OF X VALUES
C     CARD 1, COL 6-10- NPY - NO. OF Y VALUES
C     E,IFMT,AND XJ ARE READ IN SPECIAL FORMAT
C     ALL OTHER VALUES READ WITH 8F10.0 FORMAT
C
      COMMON /VANX/X(700),Y(700),XP(5),XTH(5),NP,TH(4)
      COMMON/DUMBAR/XROD1,YROD1,YROD2,NROD,NG1,NG2,ITOT,NR1,NR2
      COMMON/AGAIN/XIN(75),YIN(75),NPX,NPY,NEL
      COMMON/EXTRA/RADIUS(4),THICK(4),XJ(4),E(8),XMU(8),RHO(8),
     1    ALDATA(8),XI(2,4),VEL,AXIS,GRAV
      DIMENSION YR(2)
      LOGICAL PRINT
C
      READ (5,500) NPX,NPY,PRINT
  500 FORMAT(2I5,L1)
C
```

```
      READ (5,510) (XIN(I),I=1,NPX)
      READ (5,510) (YIN(I),I=1,NPY)
  510 FORMAT(8F10.0)
      READ (5,510) XP
      READ (5,510) XTH
      READ (5,510) TH
      READ (5,520) NROD,XROD1,YROD1,YROD2,NEOPTIN
  520 FORMAT(I10,3F10.0,I10)
      YR(1)=YROD1
      YR(2)=YROD2
      NPYM1=NPY-1
      IF (NEOPTIN.GE.1)  GO TO 30
      IF (NROD.EQ.0) GO TO 30
      DO 15 I=1,NROD
      DO 10 J=1,NPYM1
      IF (YIN(J).LT.YR(I).AND.YIN(J+1).GT.YR(I)) GO TO 5
      GO TO 10
    5 NPY=NPY+1
      JN=NPY
    7 YIN(JN)=YIN(JN-1)
      JN=JN-1
      IF (JN.GT.J+1) GO TO 7
      YIN(J+1)=YR(I)
   10 CONTINUE
   15 CONTINUE
C
C
C     READS IN ALL OF THE MATERIALS AND PROPERTIES TYPE DATA
   30 CONTINUE
      READ (5,500) IFMT
      IF (IFMT.NE.1) GO TO 100
      READ (5,540) XJ
  540 FORMAT(40X,4F10.0)
      READ (5,510) THICK,RADIUS
      READ (5,530) E
  530 FORMAT(8(2X,A8))
      READ (5,510) XMU,RHO,VEL,AXIS,GRAV
      READ (5,510) ALDATA
      IF (PRINT) CALL LISTIN
      RETURN
  100 PRINT 600
  600 FORMAT(* THIS AREA NOT IMPLEMENTED.*)
      STOP
      END
      SUBROUTINE GRID
C
C     THIS ROUTINE CALCULATES THE X-Y GRID POINTS FROM THE INPUT VALUES
C
      COMMON /VANX/X(700),Y(700),XP(5),XTH(5),NP,TH(4)
      COMMON/AGAIN/XIN(75),YIN(75),NPX,NPY,NEL
      COMMON/DUMBAR/XROD1,YROD1,YROD2,NROD,NG1,NG2,ITOT,NR1,NR2
      NP=0
      DO 15 J=1,NPY
      DO 15 K=1,NPX
      NP=NP+1
      X(NP)=XIN(K)
      Y(NP)=YIN(J)
   15 CONTINUE
```

```
C
      IF (NROD.EQ.0) GO TO 500
C
C     CALCULATE GRID VALUES FOR FIRST BAR
C
      XINC=ABS(XIN(1)-XROD1)/5.
      NG1=NP
      DO 100 J=1,5
      NG1=NG1+1
      X(NG1)=XROD1+(J-1)*XINC
      Y(NG1)=YROD1
  100 CONTINUE
C
C     DO I HAVE TO CALCULATE NEW POINTS THROUGH STRUCTURE?
      NR1=0
      DO 110 J=1,NPY
      IF (YROD1.EQ.YIN(J)) GO TO 130
  110 CONTINUE
C     NO MATCH
C     MAKE NEW GRID POINTS
      DO 120 J=1,NPX
      NG1=NG1+1
      X(NG1)=XIN(J)
      Y(NG1)=YROD1
  120 CONTINUE
      GO TO 150
  130 NR1=J
C
C     ROD 2
      NR2=0
  150 IF (NROD.LT.2) GO TO 500
      DO 170 J=1,NPY
      IF (YROD2.EQ.YIN(J)) GO TO 250
  170 CONTINUE
C     NO MATCH - NEW GRID POINTS
C
      NG2=NG1
      DO 200 J=1,NPX
      NG2=NG2+1
      X(NG2)=XIN(J)
      Y(NG2)=YROD2
  200 CONTINUE
      GO TO 500
  250 NR2=J
C     WRITE GRID CARDS
  500 ITOT=MAX0(NP,NG1,NG2)
      WRITE (7,700)(J,X(J),Y(J),J=1,ITOT)
  700 FORMAT(4HGRID,4X,I8,8X,2F8.2,8H      0.00)
      RETURN
      END
      SUBROUTINE CQUAD2
C
C     CALCULATE AND PRINT CQUAD2 CARDS
      COMMON /VANX/X(700),Y(700),XP(5),XTH(5),NP,TH(4)
      COMMON/AGAIN/XIN(75),YIN(75),NPX,NPY,NEL
      DIMENSION IGP(4)
      NEL=0
      NXL=NPX-1
```

AD-A045 701 AIR FORCE FLIGHT DYNAMICS LAB WRIGHT-PATTERSON AFB OHIO F/G 1/3
STRUCTURAL ANALYSIS OF A VANE FOR AN ADVANCED ENVIRONMENTAL CON--ETC(U)
JUN 77 K P SCHWARTZ
UNCLASSIFIED AFFDL-TR-77-49 NL

2 OF 2
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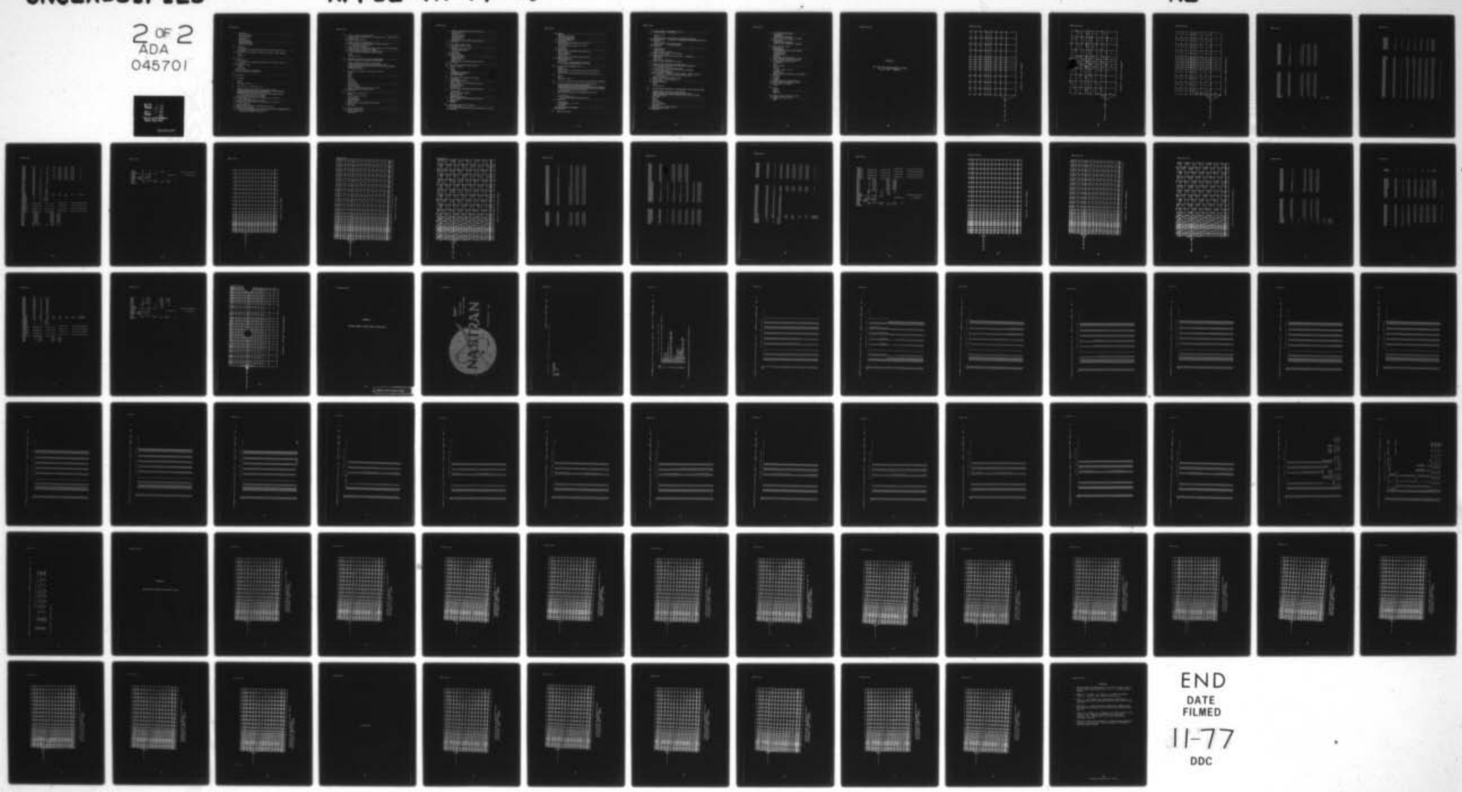

END
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```
      NYL=NPY-1
      DO 50 J=1,NYL
      IGP(1)=(J-1)*NPX
      DO 30 K=1,NXL
      NEL=NEL+1
      IGP(1)=IGP(1)+1
      IGP(2)=IGP(1)+1
      IGP(3)=IGP(2)+NPX
      IGP(4)=IGP(1)+NPX
C
C     FIND PID
      DO 5 M=1,4
      IF (X(IGP(2)).GT.XP(M).AND.X(IGP(2)).LE.XP(M+1)) GO TO 7
    5 CONTINUE
C ** SET IP=0 SO ERROR CAN BE CHECKED (THIS SHOULD NEVER HAPPEN)
      IP=0
      GO TO 10
    7 IP=M
C
C     FIND TH
   10 DO 15 M=1,4
      IF (X(IGP(2)).GT.XTH(M).AND.X(IGP(2)).LE.XTH(M+1)) GO TO 20
   15 CONTINUE
C ** DO SAME AS ABOVE
      THX=0.
      GO TO 25
   20 THX=TH(M)
   25 WRITE (7,700) NEL,IP,IGP,THX
  700 FORMAT(6HCQUAD2,2X,6I8,F8.3)
C
C
   30 CONTINUE
C
   50 CONTINUE
C
      RETURN
      END
      SUBROUTINE LISTIN
C
C     LIST WRITES ALL INPUT PARAMETERS
C
      COMMON /VANX/X(700),Y(700),XP(5),XTH(5),NP,TH(4)
      COMMON/DUMBAR/XROD1,YROD1,YROD2,NROD,NG1,NG2,IIOT,NR1,NR2
      COMMON/AGAIN/XIN(75),YIN(75),NPX,NPY,NEL
      COMMON/EXTRA/RADIUS(4),THICK(4),XJ(4),E(8),XMU(8),RHO(8),
     1    ALDATA(8),XI(2,4),VEL,AXIS,GRAV
      WRITE (6,600) NPX,(XIN(I),I=1,NPX)
  600 FORMAT(*1PROGRAM READ *,I3,* X-VALUES AS FOLLOWS--*/
     1    (10X,10F10.2))
      WRITE (6,610) NPY,(YIN(I),I=1,NPY)
  610 FORMAT(///5X,*AND READ *,I3,* Y-VALUES AS FOLLOWS--*/
     1    (10X,10F10.2))
      WRITE (6,620) XP
  620 FORMAT(///5X,*PROPERTY ID DIVISIONS--*,5F10.2)
      WRITE (6,630) XTH,TH
  630 FORMAT(///5X,*MATERIAL PROPERTY ORIENTATION ANGLE INFORMATION--*/
     1    10X,*DATA DIVISIONS--*,5F10.2/,10X,
     2    *ORIENTATION ANGLES--*,4F10.2)
```

```
C
      WRITE (6,640) XROD1,YROD1,YROD2
  640 FORMAT(///5X,*XROD1=*,F8.2,*,   YROD1=*,F8.2,*,   YROD2=*,F8.2)
      WRITE(6,699)
  699 FORMAT(///5X,*PROPERTY      1           2            3            4
     X 5           6           7           8  *  )
      WRITE (6,700) XJ,THICK,RADIUS
  700 FORMAT(///5X,*J=*,42X,4F10.3//5X,*THICK=*,4F10.3//
     1     5X,*RADIUS=*,37X,4F10.3)
      WRITE (6,710) E,XMU,RHO
  710 FORMAT(//5X,*E=*,4X,8A10//5X,*XMU=*,8F10.3//5X,*RHO=*,8F10.3)
      WRITE (6,720) VEL,AXIS,GRAV,ALDATA
  720 FORMAT(//5X,*VEL=*,F10.3,*,   AXIS=*,F10.3,
     1     *,   GRAV=*,F10.3//5X,*ALDATA=*,8F10.3)
      RETURN
      END
      SUBROUTINE CBAR
C
C     CALCULATES AND PRINTS VALUES FOR CBAR CARDS
C     SINCERE APOLOGIES TO STRUCTURED PROGRAMMING
C
      COMMON/AGAIN/XIN(75),YIN(75),NPX,NPY,NEL
      COMMON /VANX/X(700),Y(700),XP(5),XTH(5),NP,TH(4)
      COMMON/DUMBAR/XROD1,YROD1,YROD2,NROD,NG1,NG2,ITOT,NR1,NR2
      DIMENSION IGP(2)
      NFX(NN)=(NN-1)*NPX+1
C
C     CALCULATE ALL HORIZONTAL CBAR VALUES FOR ROD 1
      IPID=5
      X1=0.
      X2=1.
      X3=0.
      IF=1
      NELB=NEL
      IGP(1)=NF
      DO 50 J=1,4
      NELB=NELB+1
      IGP(1)=IGP(1)+1
      IGP(2)=IGP(1)+1
      WRITE (7,700) NELB,IPID,IGP,X1,X2,X3,IF
  700 FORMAT(4HCBAR,4X,4I8,3F8.2,I8)
   50 CONTINUE
C
C     WHERE DO I GO FROM HERE?
      IPID=7
      IF (NR1.NE.0) GO TO 100
      DO 70 J=1,NPX
      IGP(1)=IGP(1)+1
      IGP(2)=IGP(1)+1
      NELB=NELB+1
      WRITE (7,700) NELB,IPID,IGP,X1,X2,X3,IF
   70 CONTINUE
      GO TO 120
C
C     FIND OLD GRID POINTS
  100 IGP(1)=IGP(1)+1
      IGP(2)=(NR1-1)*NPX+1
      NELB=NELB+1
```

```
      WRITE (7,700) NELB,IPID,IGP,X1,X2,X3,IF
      IGP(1)=IGP(2)-1
      NPXM1=NPX-1
      DO 110 J=1,NPXM1
      IGP(1)=IGP(1)+1
      IGP(2)=IGP(1)+1
      NELB=NELB+1
      WRITE (7,700) NELB,IPID,IGP,X1,X2,X3,IF
  110 CONTINUE
C
C     DO I HAVE A SECOND ROD?
  120 IF (NROD.LT.2) GO TO 200
      IPID=8
      IF (NR2.EQ.0) GO TO 130
      IGP(1)=(NR2-1)*NPX
      GO TO 140
  130 IGP(1)=NG1
  140 NPXM1=NPX-1
      DO 150 J=1,NPXM1
      IGP(1)=IGP(1)+1
      IGP(2)=IGP(1)+1
      NELB=NELB+1
      WRITE (7,700) NELB,IPID,IGP,X1,X2,X3,IF
  150 CONTINUE
C
C     NOW FOR THE VERTICAL BARS ON ROD 1
C     FIND TIE POINT
  200 X1=1.
      X2=0.
      IPID=6
      IF (NR1.EQ.0) GO TO 250
      NUP=MIN0(3,NPY-NR1)
      NDN=MIN0(3,NR1)
C
C     CBAR CARDS FOR EXISTING GRID POINTS
      NELB=NELB+1
      IGP(1)=(NR1-2)*NPX+1
      IGP(2)=NP+5
      WRITE (7,700) NELB,IPID,IGP,X1,X2,X3,IF
      IGP(1)=IGP(2)
      IGP(2)=NR1*NPX+1
      NELB=NELB+1
      WRITE (7,700) NELB,IPID,IGP,X1,X2,X3,IF
C
      NTO=NUP+NDN
      IGP(1)=(NR1-NDN-1)*NPX+1
      DO 210 J=1,NTO
      NELB=NELB+1
      IGP(2)=IGP(1)+NPX
      WRITE (7,700) NELB,IPID,IGP,X1,X2,X3,IF
      IGP(1)=IGP(2)
  210 CONTINUE
      RETURN
C
C     CBAR CARDS FOR NEW GRID POINTS
  250 DO 260 J=2,NPY
      IF (YIN(J).GT.YROD1.AND.YIN(J-1).LT.YROD1) GO TO 265
  260 CONTINUE
```

```
  265 NTOP=J
      NBOT=J-1
      NUP=MIN0(2,NPY-NTOP)
      NDN=MIN0(2,(NBOT-1))
      IGP(1)=NFX(NBOT-NDN)
  270 IGP(2)=IGP(1)+NPX
      NELB=NELB+1
      WRITE (7,700) NELB,IPID,IGP,X1,X2,X3,IF
      IGP(1)=IGP(2)
      IF (IGP(1).EQ.NFX(NBOT)) GO TO 280
      GO TO 270
  280 IGP(2)=NP+6
      NELB=NELB+1
      WRITE (7,700) NELB,IPID,IGP,X1,X2,X3,IF
      IGP(1)=IGP(2)
      IGP(2)=NFX(NTOP)
      NELB=NELB+1
      WRITE (7,700) NELB,IPID,IGP,X1,X2,X3,IF
  290 IGP(1)=IGP(2)
      IGP(2)=IGP(1)+NPX
      NELB=NELB+1
      WRITE (7,700) NELB,IPID,IGP,X1,X2,X3,IF
      IF (IGP(2).LT.NFX(NUP+NTOP)) GO TO 290
C
C     DO TWO STRANGE DIAGONAL BARS
      IPID=5
      NELB=NELB+1
      WRITE (7,700) NELB,IPID,NFX(NBOT),NP+5,X1,X2,X3,IF
      NELB=NELB+1
      WRITE (7,700) NELB,IPID,NP+5,NFX(NTOP),X1,X2,X3,IF
C
      RETURN
      END
      SUBROUTINE CALCIN
C
C     THIS ROUTINE CALCULATES MATERIALS AND PROPERTIES TYPE DATA
C
      COMMON /VANX/X(700),Y(700),XP(5),XTH(5),NP,TH(4)
      COMMON/AGAIN/XIN(75),YIN(75),NPX,NPY,NEL
      COMMON/DUMBAR/XROD1,YROD1,YROD2,NROD,NG1,NG2,ITOT,NR1,NR2
      COMMON/EXTRA/RADIUS(4),THICK(4),XJ(4),E(8),XMU(8),RHO(8),
     1    ALDATA(8),XI(2,4),VEL,AXIS,GRAV
      DIMENSION A(4)
      DATA PI/3.14159265/,ZERO,ONE,ONENEG/0.,1.,-1./
C
      DO 10 J=1,4
      A(J)=PI*RADIUS(J)**2
          XI(1,J)=XI(2,J)=PI*RADIUS(J)**4/4.
   10 CONTINUE
C
      VELC=VEL/60.
      IF (GRAV.EQ.0)  GO TO 699
      GACEL=GRAV
      GO TO 701
  699 GACEL=ALDATA(1)*ALDATA(2)
  701 CONTINUE
C
C     WRITE EXTRA CARDS
```

```
      WRITE (7,700) (J,J,THICK(J),J=1,4)
  700 FORMAT(*PQUAD2  *,2I8,F8.4)
C
      DO 115 J=1,4
      JS=J+4
      WRITE (7,705) JS,JS,A(J),XI(1,J),J,J,XI(2,J),XJ(J)
  705 FORMAT(8HPBAR*    ,2I16,2E16.7,*QABCDEF*,I1/7H*ABCDEF,I1,2E16.7)
  115 CONTINUE
      DO 120 J=1,9
      WRITE (7,710) J,E(J),XMU(J),RHO(J)
  710 FORMAT(*MAT1    *,I8,A8,8X,2F8.4)
  120 CONTINUE
C
      IBS=NPX*NPY+1
      ITOTP1=ITOT+1
      WRITE (7,715) IBS,ITOTP1
  715 FORMAT(*SPC1*,9X,*500   123456*,2I8)
      WRITE (7,717) ITOT
  717 FORMAT(*SPC1*,9X,*501*,7X,*6*,7X,*1      THRU*,I8)
      IBS1=IBS+1
      IBS2=IBS+2
      WRITE (7,720) IBS1,IBS2
  720 FORMAT(*SPC1*,9X,*502*,7X,*2*,2I8)
C
      WRITE (7,725) ITOTP1,VELC,ONE,ZERO,ZERO
  725 FORMAT(7HRFORCE*,15X,*20*,I16,16X,E16.7,*3RFORCE1*/
     1     8H+RFORCE1, 3F8.4)
      WRITE (7,730) GACEL,ZERO,ONENEG,ZERO
  730 FORMAT(5HGRAV*,17X,*21*,16X,E16.7,F16.4,*3GRAV1*/
     1     6H+GRAV1,2X,2F8.4)
      WRITE (7,735) ONE,ONE,ONE
  735 FORMAT(*PARAM    WTMASS   .002588*/*PARAM    GRDPNT*,9X,*0*/
     1     *LOAD*,10X,*30*,2F8.4,6X,*20*,F8.4,6X,*21*)
      YAX=YIN(1)+AXIS
      WRITE (7,740) ITOTP1,ZERO,YAX,ZERO
  740 FORMAT(*GRID*,4X,I8,8X,3F8.3)
      WRITE(7,741)
  741 FORMAT(*ENDDATA*)
      RETURN
      END
      SUBROUTINE SPC
C
C     SPC CALCULATES CONSTRAINTS  FOR EACH NODE AT RIGHT EDGE OF VANE
C
      COMMON/AGAIN/XIN(75),YIN(75),NPX,NPY,NEL
      COMMON /VANX/X(700),Y(700),XP(5),XTH(5),NP,TH(4)
      COMMON/DUMBAR/XROD1,YROD1,YROD2,NROD,NG1,NG2,ITOT,NR1,NR2
      DIMENSION ISP(80)
      ISP(1)=99
      NL=0
      ICON=15
      NSPC=NPY
      DO 10 J=1,NPY
      ISP(J+1)=ISP(J)+1
      NL=NL+NPX
      WRITE (7,700) ISP(J+1),ICON,NL
  700 FORMAT(4HSPC1,4X,3I8)
   10 CONTINUE
```

```
      IF (NROD.EQ.0) GO TO 20
      IF (NR1.NE.0) GO TO 15
      NSPC=NSPC+1
      ISP(NSPC+1)=ISP(NSPC)+1
      WRITE (7,700) ISP (NSPC+1),ICON,NG1
   15 IF (NR2.NE.0) GO TO 20
      NSPC=NSPC+1
      ISP(NSPC+1)=ISP(NSPC)+1
      WRITE (7,700) ISP(NSPC+1),ICON,NG2
C
C     WRITE SPC TOTAL CARD
   20 NSPC=NSPC+4
      NCARD=NSPC/8
      IF (MOD(NSPC,8).NE.0) NCARD=NCARD+1
      ISP(NSPC-2)=500
      ISP(NSPC-1)=501
      ISP(NSPC)=502
      NCONT=10
      IF (NCARD.EQ.1) GO TO 200
      WRITE (7,710) (ISP(I),I=1,8),NCONT
  710 FORMAT(6HSPCADD,2X,8I8,3HABC,I2)
      IF (NCARD.LE.2) GO TO 100
      NCR=NCARD-1
      I1=1
      DO 50 J=1,NCR
      I1=I1+8
      IS=I1+7
      IF (IS.GE.NSPC) GO TO 70
      IO=NCONT
      NCONT=NCONT+1
      WRITE (7,720) IO,(ISP(I),I=I1,IS),NCONT
   50 CONTINUE
      I1=I1+8
   70 IS=NSPC
      IO=NCONT
  720 FORMAT(3H+BC,I2,3X,8I8,3HABC,I2)
   75 WRITE (7,730) IO,(ISP(I),I=I1,IS)
  730 FORMAT(3H+BC,I2,3X,8I8)
      RETURN
C
  100 I1=9
      IS=NSPC
      IO=10
      NCONT=11
      GO TO 75
C
  200 WRITE (7,740) (ISP(I),I=1,NSPC)
  740 FORMAT(6HSPCADD,2X,8I8)
      RETURN
      END
```

APPENDIX B

TEST CASE PLOTS AND ABBREVIATED LISTINGS FOR TEST CASES 1 THROUGH 4

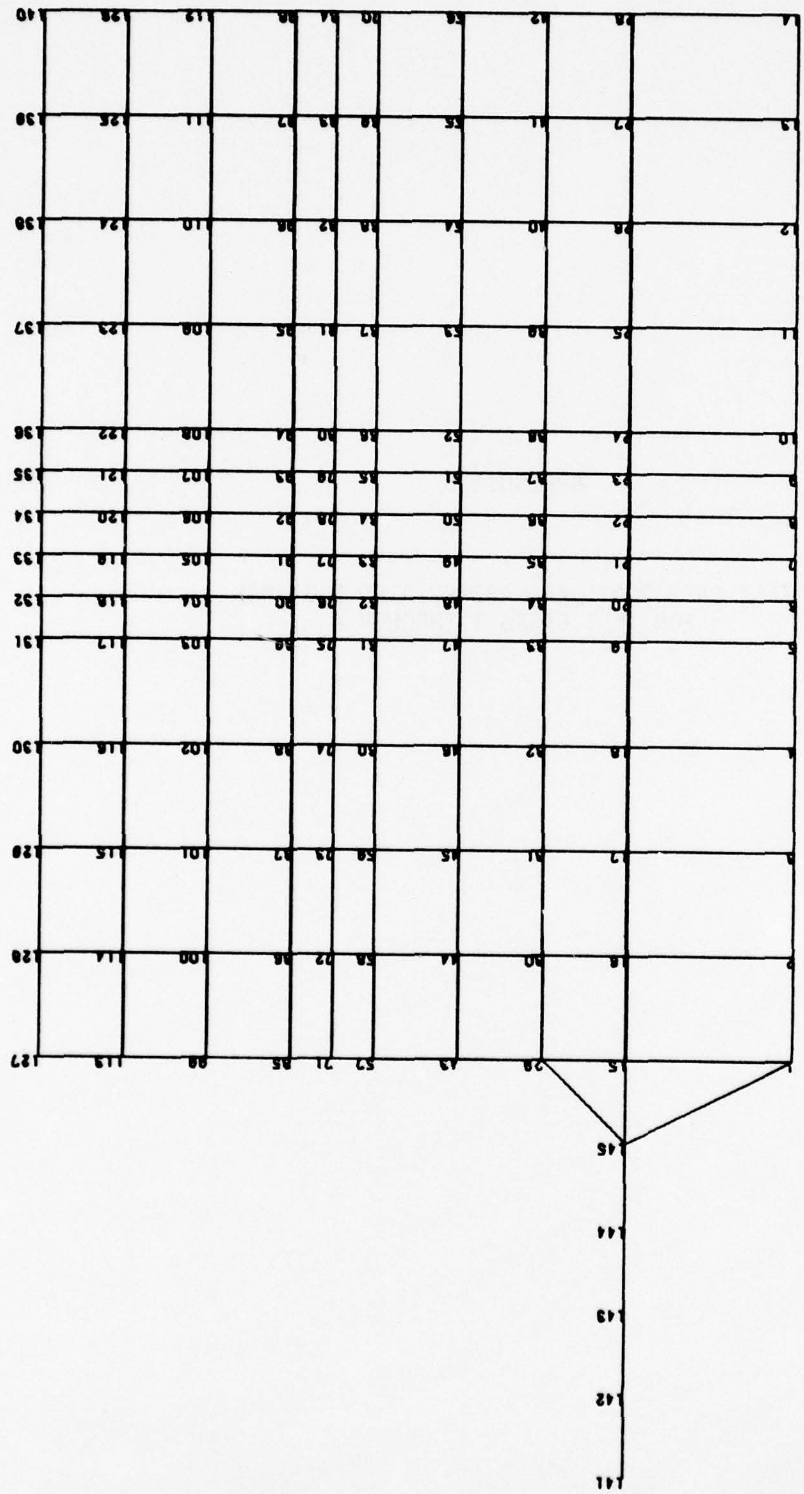

Figure B-1. Test Case 1 (Nodes)

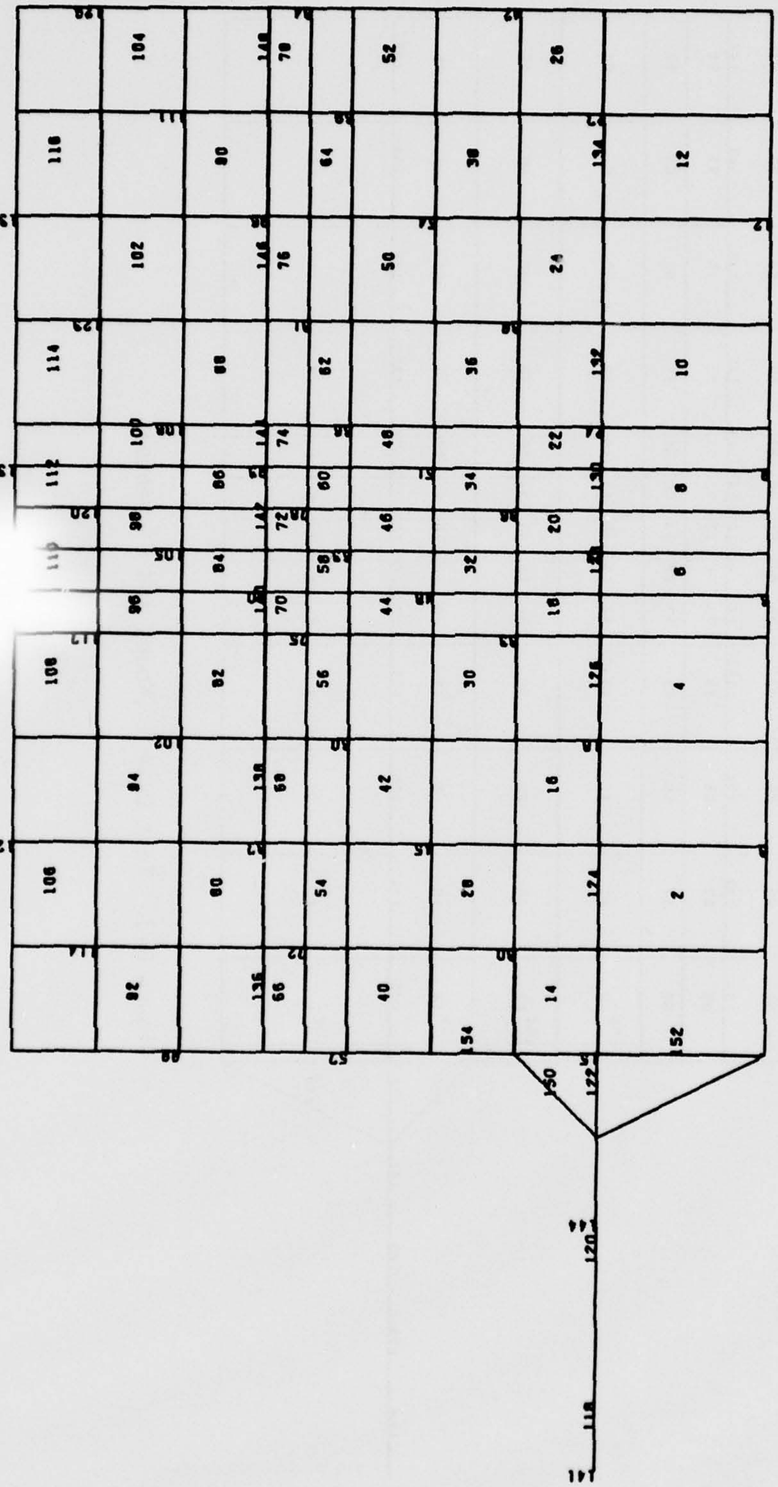

Figure B-2. Test Case 1 (Elements)

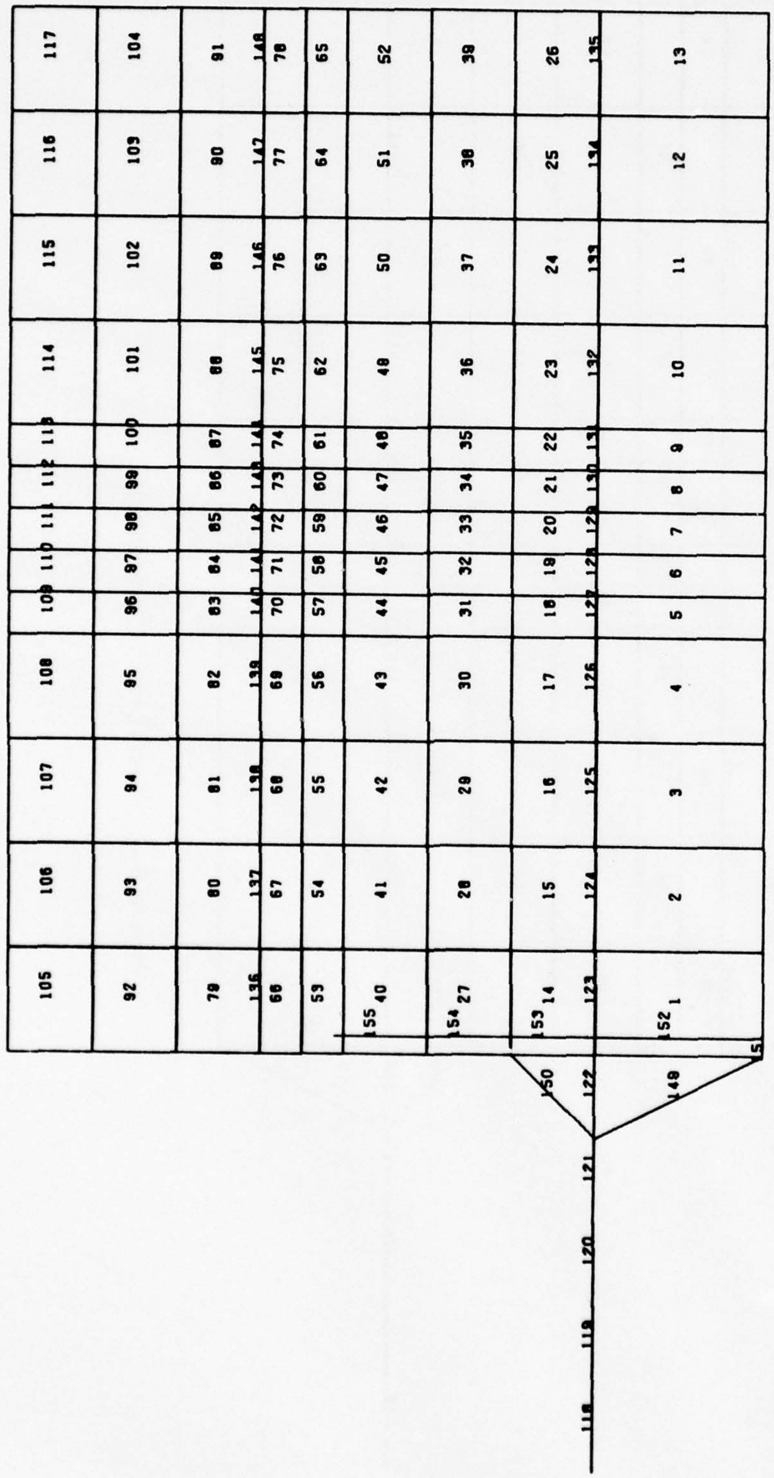

Figure B-3. Test Case 1 (Nodes and Elements)

GRID	1		0.00	0.00	0.00		
GRID	2		.25	0.00	0.00		
GRID	3		.50	0.00	0.00		
GRID	4		.75	0.00	0.00		
GRID	5		1.00	0.00	0.00		
GRID	6		1.10	0.00	0.00		
GRID	7		1.20	0.00	0.00		
GRID	8		1.30	0.00	0.00		
GRID	9		1.40	0.00	0.00		
GRID	10		1.50	0.00	0.00		
GRID	11		1.75	0.00	0.00		
GRID	12		2.00	0.00	0.00		
GRID	13		2.25	0.00	0.00		
GRID	14		2.50	0.00	0.00		
GRID	15		0.00	.40	0.00		
GRID	16		.25	.40	0.00		
GRID	129		.50	1.80	0.00		
GRID	130		.75	1.80	0.00		
GRID	131		1.00	1.80	0.00		
GRID	132		1.10	1.80	0.00		
GRID	133		1.20	1.80	0.00		
GRID	134		1.30	1.80	0.00		
GRID	135		1.40	1.80	0.00		
GRID	136		1.50	1.80	0.00		
GRID	137		1.75	1.80	0.00		
GRID	138		2.00	1.80	0.00		
GRID	139		2.25	1.80	0.00		
GRID	140		2.50	1.80	0.00		
GRID	141		-1.00	.40	0.00		
GRID	142		-.80	.40	0.00		
GRID	143		-.60	.40	0.00		
GRID	144		-.40	.40	0.00		
GRID	145		-.20	.40	0.00		
CQUAD2	1	1	1	2	16	15	0.000
CQUAD2	2	1	2	3	17	16	0.000

CQUAD2	3	2	3	4	18	17	0.000	
CQUAD2	4	2	4	5	19	18	0.000	
CQUAD2	5	3	5	6	20	19	0.000	
CQUAD2	6	3	6	7	21	20	0.000	
CQUAD2	7	4	7	8	22	21	0.000	
CQUAD2	8	4	8	9	23	22	0.000	
CQUAD2	9	4	9	10	24	23	0.000	
CQUAD2	10	4	10	11	25	24	0.000	
CQUAD2	11	4	11	12	26	25	0.000	

CQUAD2	116	4	124	125	139	138	0.000	
CQUAD2	117	4	125	126	140	139	0.000	
CBAR	118	5	141	142	0.00	1.00	0.00	1
CBAR	119	5	142	143	0.00	1.00	0.00	1
CBAR	120	5	143	144	0.00	1.00	0.00	1
CBAR	121	5	144	145	0.00	1.00	0.00	1
CBAR	122	7	145	15	0.00	1.00	0.00	1
CBAR	123	7	15	16	0.00	1.00	0.00	1
CBAR	124	7	16	17	0.00	1.00	0.00	1
CBAR	125	7	17	18	0.00	1.00	0.00	1
CBAR	126	7	18	19	0.00	1.00	0.00	1
CBAR	127	7	19	20	0.00	1.00	0.00	1
CBAR	128	7	20	21	0.00	1.00	0.00	1
CBAR	129	7	21	22	0.00	1.00	0.00	1
CBAR	130	7	22	23	0.00	1.00	0.00	1
CBAR	131	7	23	24	0.00	1.00	0.00	1
CBAR	132	7	24	25	0.00	1.00	0.00	1
CBAR	133	7	25	26	0.00	1.00	0.00	1
CBAR	134	7	26	27	0.00	1.00	0.00	1
CBAR	135	7	27	28	0.00	1.00	0.00	1
CBAR	136	8	85	86	0.00	1.00	0.00	1
CBAR	137	8	86	87	0.00	1.00	0.00	1
CBAR	138	8	87	88	0.00	1.00	0.00	1
CBAR	139	8	88	89	0.00	1.00	0.00	1
CBAR	140	8	89	90	0.00	1.00	0.00	1
CBAR	141	8	90	91	0.00	1.00	0.00	1
CBAR	142	8	91	92	0.00	1.00	0.00	1
CBAR	143	8	92	93	0.00	1.00	0.00	1
CBAR	144	8	93	94	0.00	1.00	0.00	1
CBAR	145	8	94	95	0.00	1.00	0.00	1

```
CBAR     146       6      95      96    0.00    1.00    0.00       1
CBAR     147       8      96      97    0.00    1.00    0.00       1
CBAR     148       8      97      98    0.00    1.00    0.00       1
CBAR     149       6       1     145    1.00    0.00    0.00       1
CBAR     150       6     145      29    1.00    0.00    0.00       1
CBAR     151       6     -13       1    1.00    0.00    0.00       1
CBAR     152       6       1      15    1.00    0.00    0.00       1
CBAR     153       6      15      29    1.00    0.00    0.00       1
CBAR     154       6      29      43    1.00    0.00    0.00       1
CBAR     155       6      43      57    1.00    0.00    0.00       1
SPC1     100      15      14
SPC1     101      15      28
SPC1     102      15      42
SPC1     103      15      56
SPC1     104      15      70
SPC1     105      15      84
SPC1     106      15      98
SPC1     107      15     112
SPC1     108      15     126
SPC1     109      15     140
SPCADD    99     100     101     102     103     104     105     106ABC10
+BC10    107     108     109     500     501     502
PQUAD2     1       1   .7500
PQUAD2     2       2   .7500
PQUAD2     3       3   .7500
PQUAD2     4       4   .7500
PBAR*                  5               5   .1130973E+01    .1017876E+00QABCDEF1
*ABCDEF1 .1017876E+00    .7500000E+00
PBAR*                  6               6   .2544690E+01    .5152997E+00QABCDEF2
*ABCDEF2 .5152997E+00    .3500000E+00
PBAR*                  7               7   .7068583E-01    .3976078E-03QABCDEF3
*ABCDEF3 .3976078E-03    .3500000E+00
PBAR*                  8               8   .7068583E-01    .3976078E-03QABCDEF4
*ABCDEF4 .3976078E-03    .3500000E+00
MAT1       13.0E7                  .2500   .2800
MAT1       23.0E7                  .2500   .2800
MAT1       33.0E7                  .2500   .2800
MAT1       43.0E7                  .2500   .2800
MAT1       52.8E7                  .3000   .2800
MAT1       62.8E7                  .3000   .2800
MAT1       72.8E7                  .3000   .2800
MAT1       82.8E7                  .3000   .2800
SPC1     500  123456     141     146
SPC1     501       6       1    THRU     145
```

```
SPC1          502       2      142      143
RFORCE*                20               146                      .3333333E+02QRFORCE1
+RFORCE1  1.0000   0.0000   0.0000
GRAV*                  21                       .3800000E+05          0.0000QGRAV1
+GRAV1   -1.0000   0.0000
PARAM    WTMASS   .002588
PARAM    GRDPNT         0
LOAD           30  1.0000   1.0000       20  1.0000       21
GRID          146           0.000    4.000   0.000
ENDDATA
```

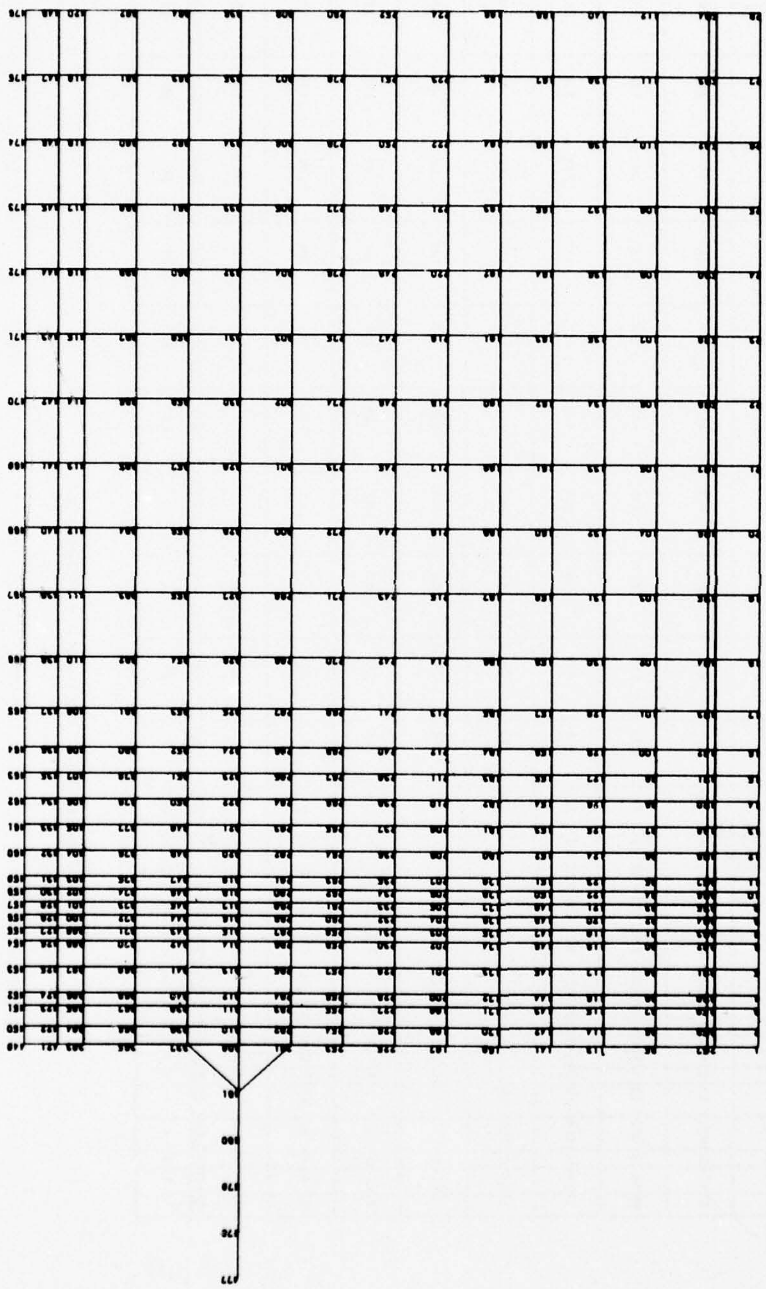

Figure B-4. Test Case 2 (Nodes)

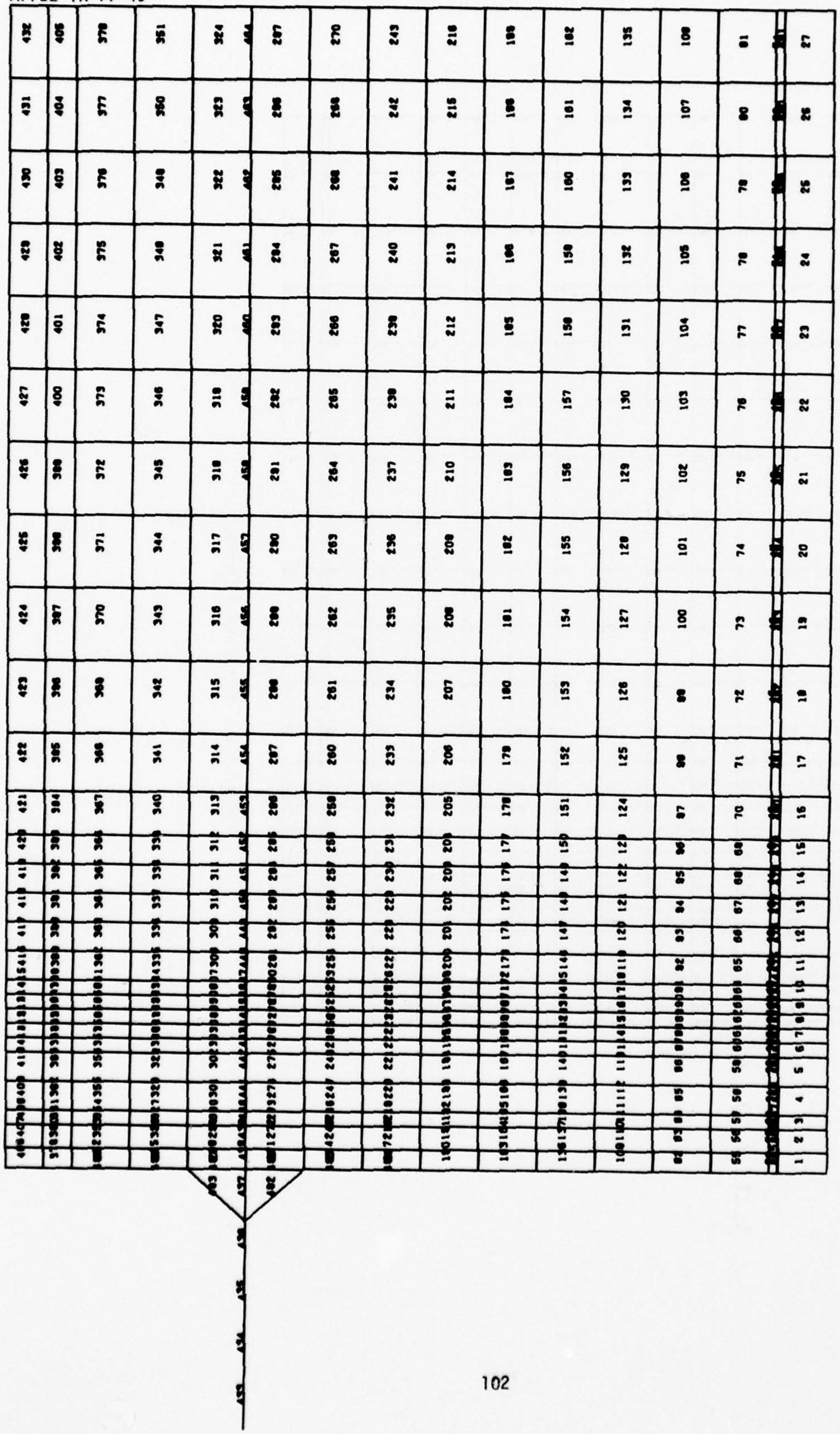

Figure B-5. Test Case 2 (Elements)

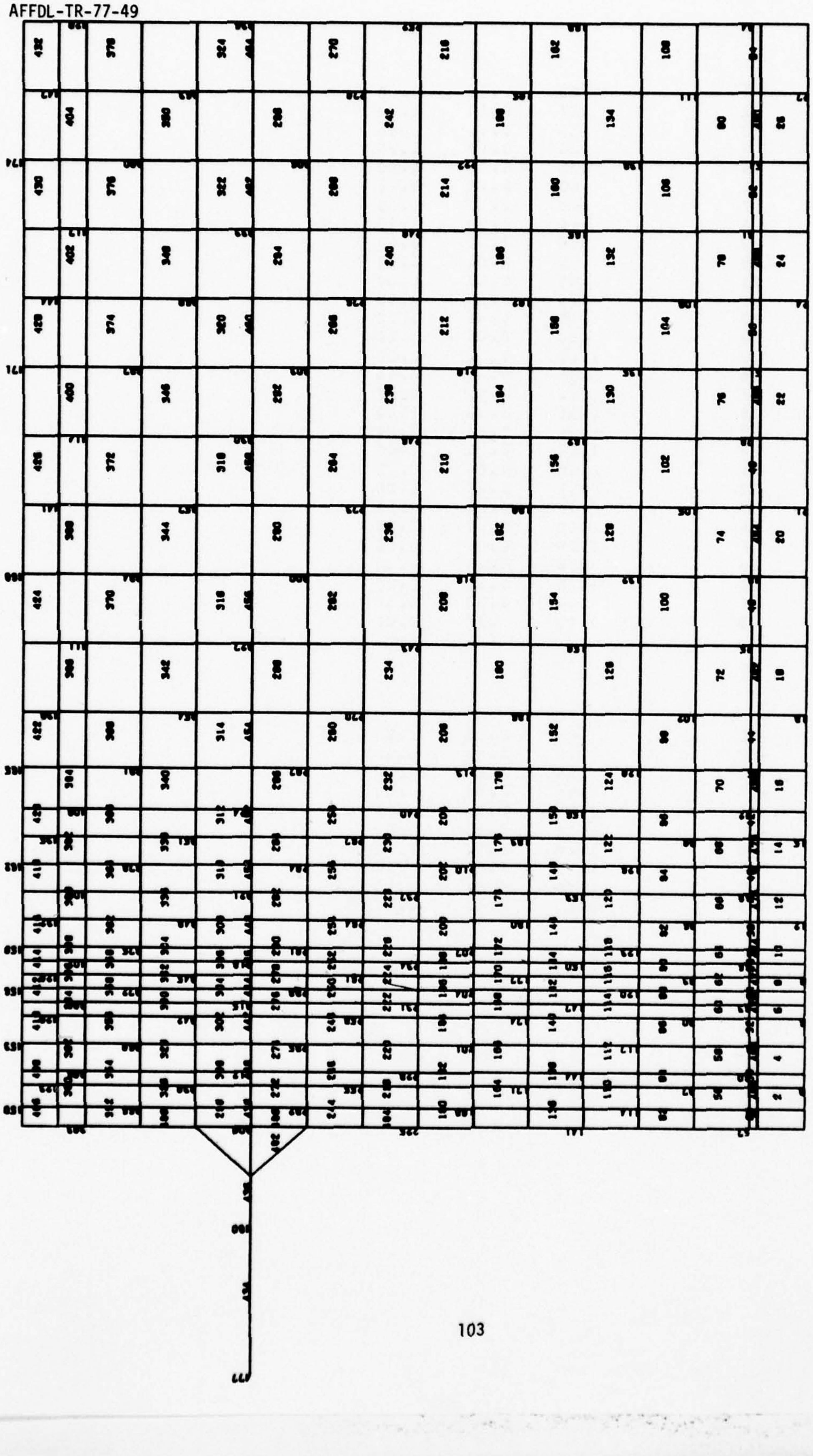

Figure B-6. Test Case 2 (Nodes and Elements)

GRID	1	0.00	0.00	0.00
GRID	2	.07	0.00	0.00
GRID	3	.15	0.00	0.00
GRID	4	.20	0.00	0.00
GRID	5	.30	0.00	0.00
GRID	6	.40	0.00	0.00
GRID	7	.45	0.00	0.00
GRID	8	.50	0.00	0.00
GRID	9	.55	0.00	0.00
GRID	10	.60	0.00	0.00
GRID	11	.65	0.00	0.00
GRID	12	.75	0.00	0.00
GRID	13	.85	0.00	0.00
GRID	14	.95	0.00	0.00
GRID	15	1.05	0.00	0.00
GRID	16	1.15	0.00	0.00
GRID	17	1.30	0.00	0.00
GRID	18	1.50	0.00	0.00
GRID	19	1.75	0.00	0.00
GRID	20	2.00	0.00	0.00
GRID	21	2.25	0.00	0.00
GRID	22	2.50	0.00	0.00
GRID	23	2.75	0.00	0.00
GRID	24	3.00	0.00	0.00
GRID	25	3.25	0.00	0.00
GRID	26	3.50	0.00	0.00
GRID	27	3.75	0.00	0.00
GRID	28	4.00	0.00	0.00
GRID	29	0.00	.17	0.00

GRID	459	.65	2.83	0.00
GRID	460	.75	2.83	0.00
GRID	461	.85	2.83	0.00
GRID	462	.95	2.83	0.00
GRID	463	1.05	2.83	0.00
GRID	464	1.15	2.83	0.00
GRID	465	1.30	2.83	0.00
GRID	466	1.50	2.83	0.00
GRID	467	1.75	2.83	0.00
GRID	468	2.00	2.83	0.00

GRID	469		2.25	2.83	0.00			
GRID	470		2.50	2.83	0.00			
GRID	471		2.75	2.83	0.00			
GRID	472		3.00	2.83	0.00			
GRID	473		3.25	2.83	0.00			
GRID	474		3.50	2.83	0.00			
GRID	475		3.75	2.83	0.00			
GRID	476		4.00	2.83	0.00			
GRID	477		-.90	2.00	0.00			
GRID	478		-.72	2.00	0.00			
GRID	479		-.54	2.00	0.00			
GRID	480		-.36	2.00	0.00			
GRID	481		-.18	2.00	0.00			
CQUAD2	1	1	1	2	30	29	0.000	
CQUAD2	2	1	2	3	31	30	0.000	
CQUAD2	3	2	3	4	32	31	0.000	
CQUAD2	4	2	4	5	33	32	0.000	
CQUAD2	5	2	5	6	34	33	0.000	
CQUAD2	6	2	6	7	35	34	0.000	
CQUAD2	7	2	7	8	36	35	0.000	
CQUAD2	8	2	8	9	37	36	0.000	
CQUAD2	9	2	9	10	38	37	0.000	
CQUAD2	10	2	10	11	39	38	0.000	
CQUAD2	11	3	11	12	40	39	0.000	
CQUAD2	12	3	12	13	41	40	0.000	
CQUAD2	13	3	13	14	42	41	0.000	
CQUAD2	14	3	14	15	43	42	0.000	
CQUAD2	15	3	15	16	44	43	0.000	
CQUAD2	424	3	439	440	468	467	0.000	
CQUAD2	425	4	440	441	469	468	0.000	
CQUAD2	426	4	441	442	470	469	0.000	
CQUAD2	427	4	442	443	471	470	0.000	
CQUAD2	428	4	443	444	472	471	0.000	
CQUAD2	429	4	444	445	473	472	0.000	
CQUAD2	430	4	445	446	474	473	0.000	
CQUAD2	431	4	446	447	475	474	0.000	
CQUAD2	432	4	447	448	476	475	0.000	
CBAR	433	5	477	478	0.00	1.00	0.00	1
CBAR	434	5	478	479	0.00	1.00	0.00	1

CBAR	435	5	479	480	0.00	1.00	0.00	1	
CBAR	436	5	480	481	0.00	1.00	0.00	1	
CBAR	437	7	481	309	0.00	1.00	0.00	1	
CBAR	438	7	309	310	0.00	1.00	0.00	1	
CBAR	439	7	310	311	0.00	1.00	0.00	1	
CBAR	440	7	311	312	0.00	1.00	0.00	1	
CBAR	441	7	312	313	0.00	1.00	0.00	1	
CBAR	442	7	313	314	0.00	1.00	0.00	1	
CBAR	443	7	314	315	0.00	1.00	0.00	1	
CBAR	444	7	315	316	0.00	1.00	0.00	1	
CBAR	445	7	316	317	0.00	1.00	0.00	1	

CBAR	496	6	281	309	1.00	0.00	0.00	1	
CBAR	497	6	309	337	1.00	0.00	0.00	1	
CBAR	498	6	337	365	1.00	0.00	0.00	1	
CBAR	499	6	365	393	1.00	0.00	0.00	1	
SPC1	100	15	28						
SPC1	101	15	56						
SPC1	102	15	84						
SPC1	103	15	112						
SPC1	104	15	140						
SPC1	105	15	168						
SPC1	106	15	196						
SPC1	107	15	224						
SPC1	108	15	252						
SPC1	109	15	280						
SPC1	110	15	308						
SPC1	111	15	336						
SPC1	112	15	364						
SPC1	113	15	392						
SPC1	114	15	420						
SPC1	115	15	448						
SPC1	116	15	476						
SPCADD	99	100	101	102	103	104	105	106	ABC10
+BC10	107	108	109	110	111	112	113	114	ABC11
+BC11	115	116	500	501	502				
PQUAD2	1	1	.3740						
PQUAD2	2	2	.3740						
PQUAD2	3	3	.3740						
PQUAD2	4	4	.3740						

```
PBAR*                  5                      5  .1256637E+00    .1256637E-02QABCDEF1
*ABCDEF1  .1256637E-02     .4000000E+00
PBAR*                  6                      6  .3141593E-01    .7853982E-04QABCDEF2
*ABCDEF2  .7853982E-04     .2000000E+00
PBAR*                  7                      7  .1410261E-01    .1582665E-04QABCDEF3
*ABCDEF3  .1582665E-04     .1250000E+00
PBAR*                  8                      8  .7068218E-02    .3998198E-05QABCDEF4
*ABCDEF4  .3998198E-05     .9500000E-01
MAT1           1   3.0E7           .3200   .2800
MAT1           2   1.0E7           .3000   .1500
MAT1           3   3.5E6           .2800   .0660
MAT1           4   3.5E6           .2800   .0660
MAT1           5   3.0E7           .3200   .2800
MAT1           6   3.0E7           .3200   .2800
MAT1           7   3.0E7           .3200   .2800
MAT1           8   3.0E7           .3200   .2800
SPC1         500  123456     477     482
SPC1         501       6       1    THRU     481
SPC1         502       2     478     479
RFORCE*               20                    482                  .3333333E+02QRFORCE1
+RFORCE1  0.0000  0.0000  1.0000
GRAV*                 21                         .1340000E+06          0.0000QGRAV1
+GRAV1    1.0000  0.0000
PARAM   WTMASS   .002588
PARAM   GRDPNT         0
LOAD          30  1.0000  1.0000      20  1.0000      21
GRID         482          0.000   4.000   0.000
ENDDATA
```

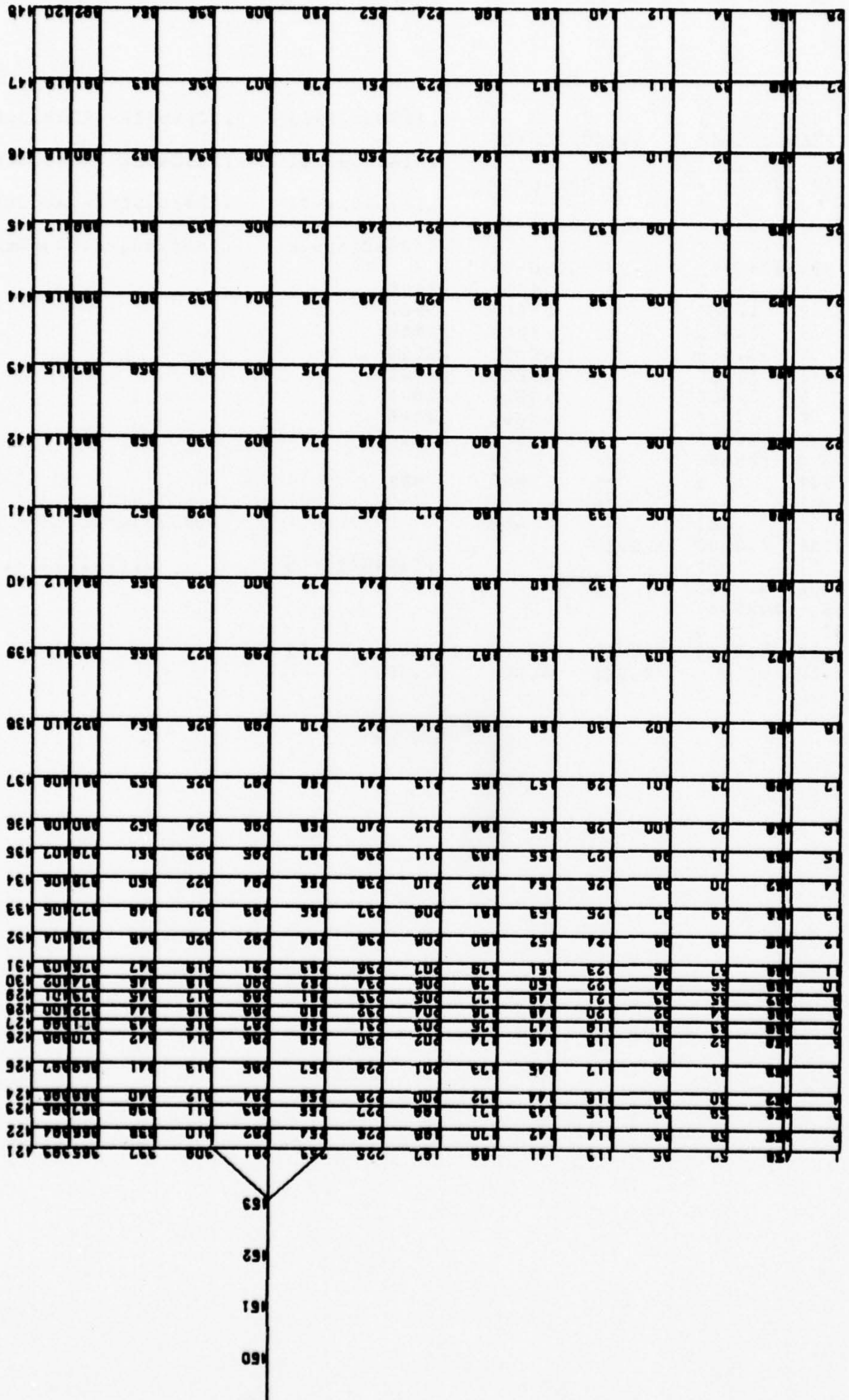

Figure B-7. Test Case 3 (Nodes)

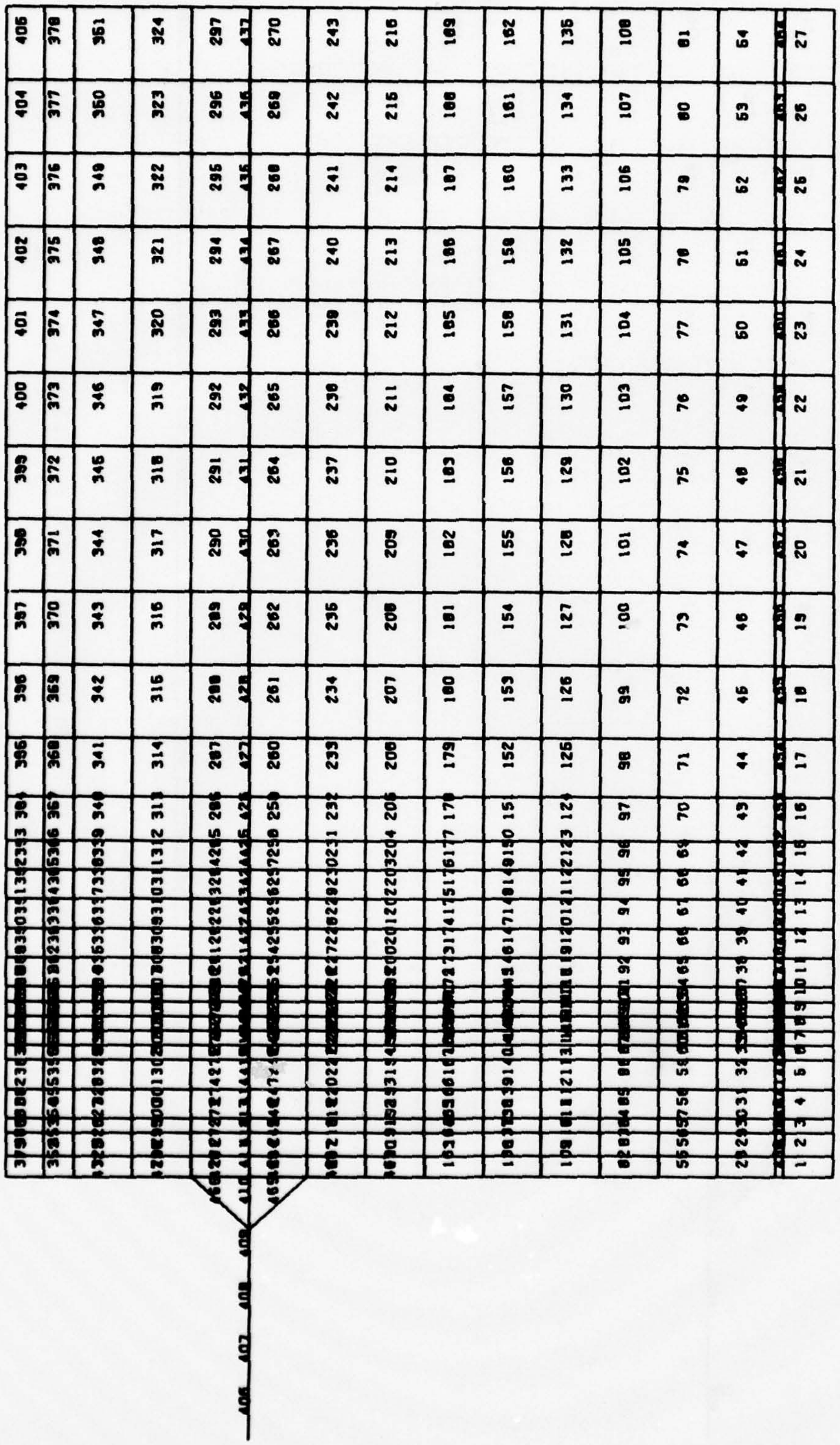

Figure B-8. Test Case 3 (Elements)

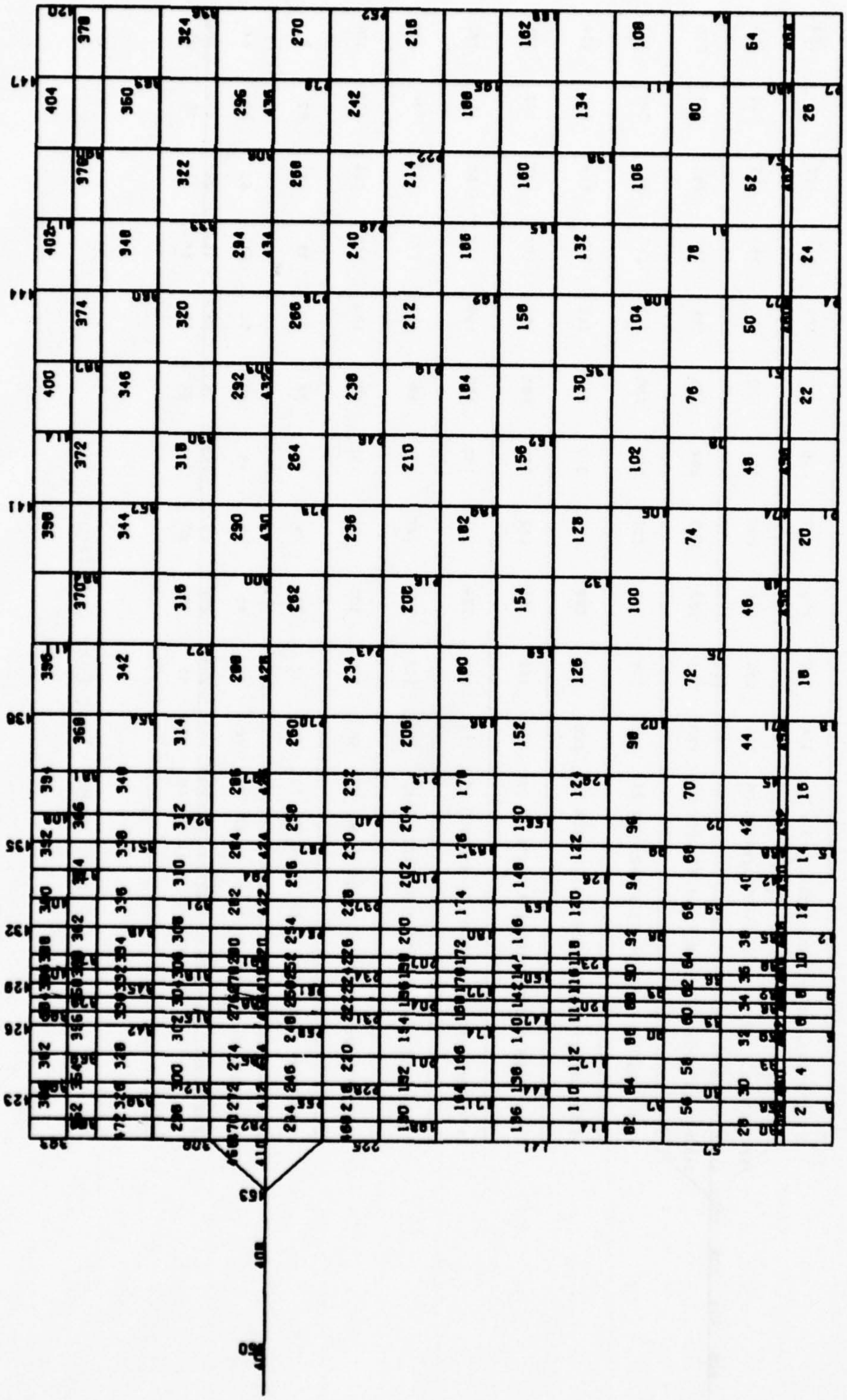

Figure B-9. Test Case 3 (Nodes and Elements)

GRID	1		0.00	0.00	0.00		
GRID	2		.07	0.00	0.00		
GRID	3		.15	0.00	0.00		
GRID	4		.20	0.00	0.00		
GRID	5		.30	0.00	0.00		
GRID	6		.40	0.00	0.00		
GRID	7		.45	0.00	0.00		
GRID	8		.50	0.00	0.00		
GRID	9		.55	0.00	0.00		
GRID	10		.60	0.00	0.00		
GRID	11		.65	0.00	0.00		
GRID	12		.75	0.00	0.00		
GRID	13		.85	0.00	0.00		
GRID	14		.95	0.00	0.00		
GRID	15		1.05	0.00	0.00		
GRID	16		1.15	0.00	0.00		
GRID	17		1.30	0.00	0.00		

GRID	468		1.05	.17	0.00		
GRID	469		1.15	.17	0.00		
GRID	470		1.30	.17	0.00		
GRID	471		1.50	.17	0.00		
GRID	472		1.75	.17	0.00		
GRID	473		2.00	.17	0.00		
GRID	474		2.25	.17	0.00		
GRID	475		2.50	.17	0.00		
GRID	476		2.75	.17	0.00		
GRID	477		3.00	.17	0.00		
GRID	478		3.25	.17	0.00		
GRID	479		3.50	.17	0.00		
GRID	480		3.75	.17	0.00		
GRID	481		4.00	.17	0.00		
CQUAD2	1	1	1	2	30	29	0.000
CQUAD2	2	1	2	3	31	30	0.000
CQUAD2	3	2	3	4	32	31	0.000
CQUAD2	4	2	4	5	33	32	0.000

CQUAD2	5	2	5	6	34	33	0.000	
CQUAD2	6	2	6	7	35	34	0.000	

CQUAD2	399	4	413	414	442	441	0.000	
CQUAD2	400	4	414	415	443	442	0.000	
CQUAD2	401	4	415	416	444	443	0.000	
CQUAD2	402	4	416	417	445	444	0.000	
CQUAD2	403	4	417	418	446	445	0.000	
CQUAD2	404	4	418	419	447	446	0.000	
CQUAD2	405	4	419	420	448	447	0.000	
CBAR	406	5	449	450	0.00	1.00	0.00	1
CBAR	407	5	450	451	0.00	1.00	0.00	1
CBAR	408	5	451	452	0.00	1.00	0.00	1
CBAR	409	5	452	453	0.00	1.00	0.00	1
CBAR	410	7	453	281	0.00	1.00	0.00	1
CBAR	411	7	281	282	0.00	1.00	0.00	1
CBAR	412	7	282	283	0.00	1.00	0.00	1

CBAR	460	8	476	477	0.00	1.00	0.00	1
CBAR	461	8	477	478	0.00	1.00	0.00	1
CBAR	462	8	478	479	0.00	1.00	0.00	1
CBAR	463	8	479	480	0.00	1.00	0.00	1
CBAR	464	8	480	481	0.00	1.00	0.00	1
CBAR	465	6	253	453	1.00	0.00	0.00	1
CBAR	466	6	453	309	1.00	0.00	0.00	1
CBAR	467	6	197	225	1.00	0.00	0.00	1
CBAR	468	6	225	253	1.00	0.00	0.00	1
CBAR	469	6	253	281	1.00	0.00	0.00	1
CBAR	470	6	281	309	1.00	0.00	0.00	1
CBAR	471	6	309	337	1.00	0.00	0.00	1
CBAR	472	6	337	365	1.00	0.00	0.00	1
SPC1	100	15	28					
SPC1	101	15	56					
SPC1	102	15	84					

```
SPC1         103      15     112
SPC1         104      15     140
SPC1         105      15     168
SPC1         106      15     196
SPC1         107      15     224
SPC1         108      15     252
SPC1         109      15     280
SPC1         110      15     308
SPC1         111      15     336
SPC1         112      15     364
SPC1         113      15     392
SPC1         114      15     420
SPC1         115      15     448
SPC1         116      15     461
SPCADD        99     100     101     102     103     104     105     106ABC10
+BC10        107     108     109     110     111     112     113     114ABC11
+BC11        115     116     500     501     502
PQUAD2         1       1   .3740
PQUAD2         2       2   .3740
PQUAD2         3       3   .3740
PQUAD2         4       4   .3740
PBAR*                  5               5   .1256637E+00    .1256637E-02QABCDEF1
*ABCDEF1     .1256637E-02  .4000000E+00
PBAR*                  6               6   .3141593E-01    .7853982E-04QABCDEF2
*ABCDEF2     .7853982E-04  .2000000E+00
PBAR*                  7               7   .1410261E-01    .1582665E-04QABCDEF3
*ABCDEF3     .1582665E-04  .1250000E+00
PBAR*                  8               8   .7088218E-02    .3998198E-05QABCDEF4
*ABCDEF4     .3998198E-05  .9500000E-01
MAT1           1   3.0E7           .3200   .2800
MAT1           2   1.0E7           .3000   .1500
MAT1           3   3.5E6           .2800   .0660
MAT1           4   3.5E6           .2800   .0660
```

```
MAT1           5   3.0E7             .3200   .2800
MAT1           6   3.0E7             .3200   .2800
MAT1           7   3.0E7             .3200   .2800
MAT1           8   3.0E7             .3200   .2800
SPC1         500  123456      449      482
SPC1         501       6        1     THRU     481
SPC1         502       2      450      451
RFORCE*               20               482                       .5130007E+03QRFORCE1
+RFORCE1  1.0000  0.0000   0.0000
GRAV*                 21                     .3600000E+06         0.0000QGRAV1
+GRAV1   -1.0000  0.0000
PARAM    WTMASS  .002566
PARAM    GROPNT        0
LOAD          30  1.0000   1.0000       20  1.0000      21
GRID         482            0.000    5.500   0.000
ENDDATA
```

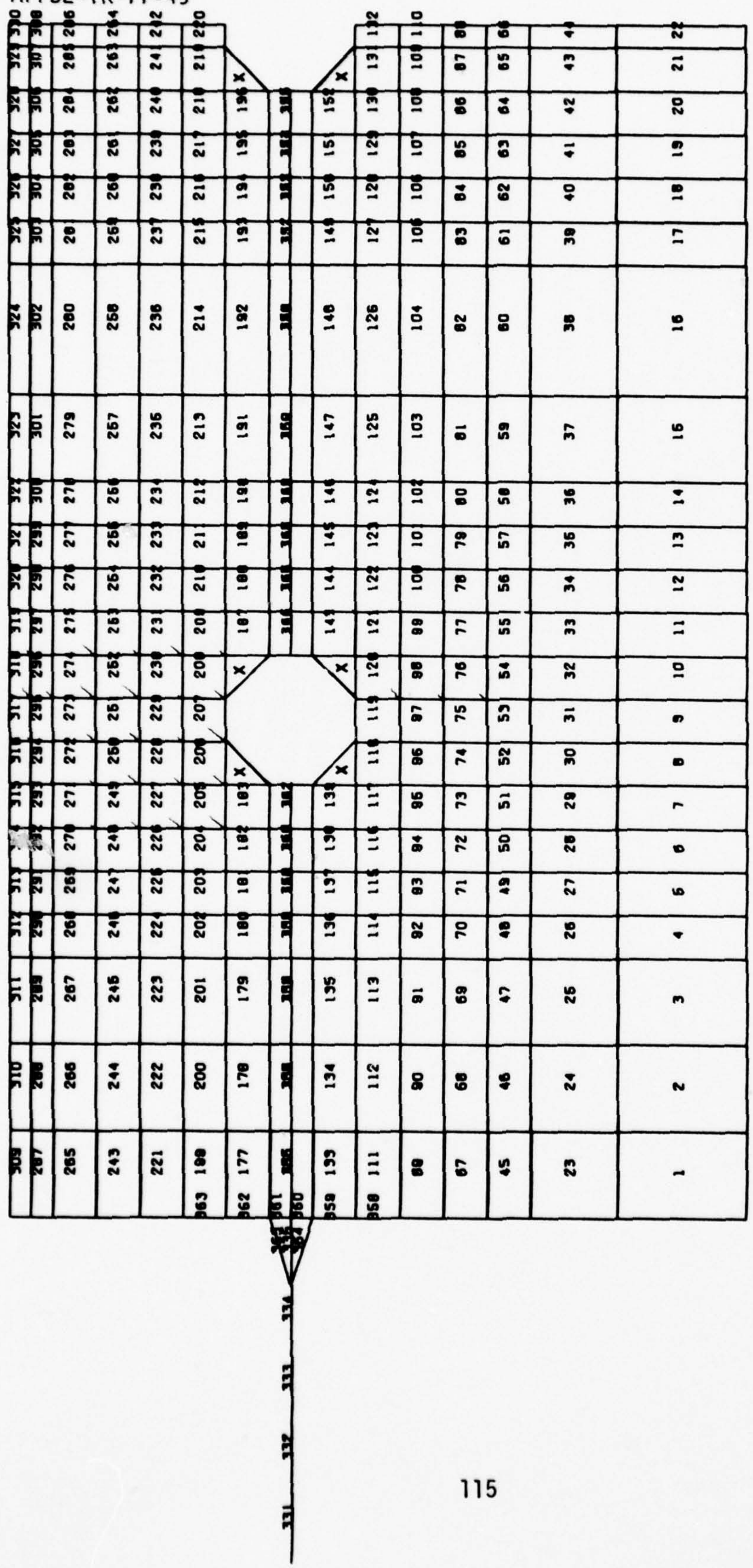

Figure B-10. Test Case 4 (Nodes and Elements)

APPENDIX C

NASTRAN PROGRAM LISTINGS FROM A SORTED INPUT

CDC 6000 SERIES
MODEL 6600

RIGID FORMAT SERIES 4

LEVEL 15.2.0 (NAVY NASTRAN)

SYSTEM GENERATION DATE - 9/16/74

DECEMBER 22, 1976 NASTRAN 9/16/74 PAGE 1

N A S T R A N   E X E C U T I V E   C O N T R O L   D E C K   E C H O

```
ID   ROVAC,SCHWARTZ
APP     DISPLACEMENT
SOL     1,0
DIAG    13
TIME    100
CEND
```

```
K.P.SCHWARTZ, 60% SIZE #7D ( 0 DEG.=3,+45,-45,90 DEG.  LAYERS ) AS     DECEMBER  22, 1976   NASTRAN  9/16/74    PAGE     2

                              C A S E   C O N T R O L   D E C K   E C H O
     CARD
     COUNT
       1      TITLE=K.P.SCHWARTZ, 60% SIZE #7D ( 0 DEG.=3,+45,-45,90 DEG.  LAYERS ) AS
       2      OUTPUT
       3      OLOAD = ALL
       4      SPCFORCES = ALL
       5      ELFORCES  = ALL
       6      STRESSES = ALL
       7      DISPLACEMENT(PRINT,PUNCH) = ALL
       8      SUBCASE 1
       9      SUBTITLE= ACTUAL AIR CYCLE VANE (COMBINED LOADS)
      10      LABEL=ROVAC,RUN TEST CASE #2  AFFDL/FEMC, SCHWARTZ
      11      LOAD=  30
      12      SPC=99
      13      OUTPUT(PLOT)
      14      SET 1=ALL
      15      PLOTTER NASTPLT (D,1)
      16      ORTHOGRAPHIC PROJECTION
      17      VIEW 90.0,90.0,0.0
      18      FIND SCALE, ORIGIN 1
      19      MAXIMUM DEFORMATION= .2
      20      PLOT STATIC DEFORMATION 0,1,SET 1,SHAPE
      21      PLOT STATIC DEFORMATION 1,SET 1,SHAPE
      22      BEGIN BULK

*** USER INFORMATION MESSAGE 207, BULK DATA NOT SORTED,XSORT WILL RE-ORDER DECK.
```

K.P.SCHWARTZ, 60% SIZE #7D (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS DECEMBER 22, 1976 NASTRAN 9/16/74 PAGE 3

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 .. 10 .
1-	CBAR	433	5	477	478	.00	1.00	.00	1
2-	CBAR	434	5	478	479	.00	1.00	.00	1
3-	CBAR	435	5	479	480	.00	1.00	.00	1
4-	CBAR	436	5	480	481	.00	1.00	.00	1
5-	CBAR	437	9	481	309	.00	1.00	.00	1
6-	CBAR	438	7	309	310	.00	1.00	.00	1
7-	CBAR	439	7	310	311	.00	1.00	.00	1
8-	CBAR	440	7	311	312	.00	1.00	.00	1
9-	CBAR	441	7	312	313	.00	1.00	.00	1
10-	CBAR	442	7	313	314	.00	1.00	.00	1
11-	CBAR	443	7	314	315	.00	1.00	.00	1
12-	CBAR	444	7	315	316	.00	1.00	.00	1
13-	CBAR	445	7	316	317	.00	1.00	.00	1
14-	CBAR	446	7	317	318	.00	1.00	.00	1
15-	CBAR	447	7	318	319	.00	1.00	.00	1
16-	CBAR	448	7	319	320	.00	1.00	.00	1
17-	CBAR	449	7	320	321	.00	1.00	.00	1
18-	CBAR	450	7	321	322	.00	1.00	.00	1
19-	CBAR	451	7	322	323	.00	1.00	.00	1
20-	CBAR	452	7	323	324	.00	1.00	.00	1
21-	CBAR	453	7	324	325	.00	1.00	.00	1
22-	CBAR	454	7	325	326	.00	1.00	.00	1
23-	CBAR	455	7	326	327	.00	1.00	.00	1
24-	CBAR	456	7	327	328	.00	1.00	.00	1
25-	CBAR	457	7	328	329	.00	1.00	.00	1
26-	CBAR	458	7	329	330	.00	1.00	.00	1
27-	CBAR	459	7	330	331	.00	1.00	.00	1
28-	CBAR	460	7	331	332	.00	1.00	.00	1
29-	CBAR	461	7	332	333	.00	1.00	.00	1
30-	CBAR	462	7	333	334	.00	1.00	.00	1
31-	CBAR	463	7	334	335	.00	1.00	.00	1
32-	CBAR	464	7	335	336	.00	1.00	.00	1
33-	CBAR	465	8	29	30	.00	1.00	.00	1
34-	CBAR	466	8	30	31	.00	1.00	.00	1
35-	CBAR	467	8	31	32	.00	1.00	.00	1
36-	CBAR	468	8	32	33	.00	1.00	.00	1
37-	CBAR	469	8	33	34	.00	1.00	.00	1
38-	CBAR	470	8	34	35	.00	1.00	.00	1
39-	CBAR	471	8	35	36	.00	1.00	.00	1
40-	CBAR	472	8	36	37	.00	1.00	.00	1
41-	CBAR	473	8	37	38	.00	1.00	.00	1
42-	CBAR	474	8	38	39	.00	1.00	.00	1
43-	CBAR	475	8	39	40	.00	1.00	.00	1
44-	CBAR	476	8	40	41	.00	1.00	.00	1
45-	CBAR	477	8	41	42	.00	1.00	.00	1
46-	CBAR	478	8	42	43	.00	1.00	.00	1
47-	CBAR	479	8	43	44	.00	1.00	.00	1
48-	CBAR	480	8	44	45	.00	1.00	.00	1
49-	CBAR	481	8	45	46	.00	1.00	.00	1
50-	CBAR	482	8	46	47	.00	1.00	.00	1

S O R T E D B U L K D A T A E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
51-	CBAR	483	8	47	48	.00	1.00	.00	1	
52-	CBAR	484	8	48	49	.00	1.00	.00	1	
53-	CBAR	485	8	49	50	.00	1.00	.00	1	
54-	CBAR	486	8	50	51	.00	1.00	.00	1	
55-	CBAR	487	8	51	52	.00	1.00	.00	1	
56-	CBAR	488	8	52	53	.00	1.00	.00	1	
57-	CBAR	489	8	53	54	.00	1.00	.00	1	
58-	CBAR	490	8	54	55	.00	1.00	.00	1	
59-	CBAR	431	8	55	56	.00	1.00	.00	1	
60-	CBAR	492	6	281	481	1.00	.00	.00	1	
61-	CBAR	493	6	481	337	1.00	.00	.00	1	
62-	CBAR	494	6	225	253	1.00	.00	.00	1	
63-	CBAR	495	6	253	281	1.00	.00	.00	1	
64-	CBAR	496	6	281	309	1.00	.00	.00	1	
65-	CBAR	497	6	309	337	1.00	.00	.00	1	
66-	CBAR	498	6	337	365	1.00	.00	.00	1	
67-	CBAR	499	6	365	393	1.00	.00	.00	1	
68-	CQUAD2	1	1	1	2	30	29	0.000		
69-	CQUAD2	2	1	2	3	31	30	0.000		
70-	CQUAD2	3	2	3	4	32	31	0.000		
71-	CQUAD2	4	2	4	5	33	32	0.000		
72-	CQUAD2	5	2	5	6	34	33	0.000		
73-	CQUAD2	6	2	6	7	35	34	0.000		
74-	CQUAD2	7	2	7	8	36	35	0.000		
75-	CQUAD2	8	2	8	9	37	36	0.000		
76-	CQUAD2	9	2	9	10	38	37	0.000		
77-	CQUAD2	10	2	10	11	39	38	0.000		
78-	CQUAD2	11	3	11	12	40	39	0.000		
79-	CQUAD2	12	3	12	13	41	40	0.000		
80-	CQUAD2	13	3	13	14	42	41	0.000		
81-	CQUAD2	14	3	14	15	43	42	0.000		
82-	CQUAD2	15	3	15	16	44	43	0.000		
83-	CQUAD2	16	3	16	17	45	44	0.000		
84-	CQUAD2	17	3	17	18	46	45	0.000		
85-	CQUAD2	18	3	18	19	47	46	0.000		
86-	CQUAD2	19	3	19	20	48	47	0.000		
87-	CQUAD2	20	4	20	21	49	48	0.000		
88-	CQUAD2	21	4	21	22	50	49	0.000		
89-	CQUAD2	22	4	22	23	51	50	0.000		
90-	CQUAD2	23	4	23	24	52	51	0.000		
91-	CQUAD2	24	4	24	25	53	52	0.000		
92-	CQUAD2	25	4	25	26	54	53	0.000		
93-	CQUAD2	26	4	26	27	55	54	0.000		
94-	CQUAD2	27	4	27	28	56	55	0.000		
95-	CQUAD2	28	1	29	30	58	57	0.000		
96-	CQUAD2	29	1	30	31	59	58	0.000		
97-	CQUAD2	30	2	31	32	60	59	0.000		
98-	CQUAD2	31	2	32	33	61	60	0.000		
99-	CQUAD2	32	2	33	34	62	61	0.000		
100-	CQUAD2	33	2	34	35	63	62	0.000		

K.P.SCHWARTZ, 60% SIZE #7D (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS DECEMBER 22, 1976 NASTRAN 9/16/74 PAGE 5

SORTED BULK DATA ECHO

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
101-	CQUAD2	34	2	35	36	64	63	0.000		
102-	CQUAD2	35	2	36	37	65	64	0.000		
103-	CQUAD2	36	2	37	38	66	65	0.000		
104-	CQUAD2	37	2	38	39	67	66	0.000		
105-	CQUAD2	38	3	39	40	68	67	0.000		
106-	CQUAD2	39	3	40	41	69	68	0.000		
107-	CQUAD2	40	3	41	42	70	69	0.000		
108-	CQUAD2	41	3	42	43	71	70	0.000		
109-	CQUAD2	42	3	43	44	72	71	0.000		
110-	CQUAD2	43	3	44	45	73	72	0.000		
111-	CQUAD2	44	3	45	46	74	73	0.000		
112-	CQUAD2	45	3	46	47	75	74	0.000		
113-	CQUAD2	46	3	47	48	76	75	0.000		
114-	CQUAD2	47	4	48	49	77	76	0.000		
115-	CQUAD2	48	4	49	50	78	77	0.000		
116-	CQUAD2	49	4	50	51	79	78	0.000		
117-	CQUAD2	50	4	51	52	80	79	0.000		
118-	CQUAD2	51	4	52	53	81	80	0.000		
119-	CQUAD2	52	4	53	54	82	81	0.000		
120-	CQUAD2	53	4	54	55	83	82	0.000		
121-	CQUAD2	54	4	55	56	84	83	0.000		
122-	CQUAD2	55	1	57	58	86	85	0.000		
123-	CQUAD2	56	1	58	59	87	86	0.000		
124-	CQUAD2	57	2	59	60	88	87	0.000		
125-	CQUAD2	58	2	60	61	89	88	0.000		
126-	CQUAD2	59	2	61	62	90	89	0.000		
127-	CQUAD2	60	2	62	63	91	90	0.000		
128-	CQUAD2	61	2	63	64	92	91	0.000		
129-	CQUAD2	62	2	64	65	93	92	0.000		
130-	CQUAD2	63	2	65	66	94	93	0.000		
131-	CQUAD2	64	2	66	67	95	94	0.000		
132-	CQUAD2	65	3	67	68	96	95	0.000		
133-	CQUAD2	66	3	68	69	97	96	0.000		
134-	CQUAD2	67	3	69	70	98	97	0.000		
135-	CQUAD2	68	3	70	71	99	98	0.000		
136-	CQUAD2	69	3	71	72	100	99	0.000		
137-	CQUAD2	70	3	72	73	101	100	0.000		
138-	CQUAD2	71	3	73	74	102	101	0.000		
139-	CQUAD2	72	3	74	75	103	102	0.000		
140-	CQUAD2	73	3	75	76	104	103	0.000		
141-	CQUAD2	74	4	76	77	105	104	0.000		
142-	CQUAD2	75	4	77	78	106	105	0.000		
143-	CQUAD2	76	4	78	79	107	106	0.000		
144-	CQUAD2	77	4	79	80	108	107	0.000		
145-	CQUAD2	78	4	80	81	109	108	0.000		
146-	CQUAD2	79	4	81	82	110	109	0.000		
147-	CQUAD2	80	4	82	83	111	110	0.000		
148-	CQUAD2	81	4	83	84	112	111	0.000		
149-	CQUAD2	82	1	85	86	114	113	0.000		
150-	CQUAD2	83	1	86	87	115	114	0.000		

K.P.SCHWARTZ, 60% SIZE #7D (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS DECEMBER 22, 1976 NASTRAN 9/16/74 PAGE 6

S O R T E D B U L K D A T A E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
151-	CQUAD2	84	2	87	88	116	115	0.000		
152-	CQUAD2	85	2	88	89	117	116	0.000		
153-	CQUAD2	86	2	89	90	118	117	0.000		
154-	CQUAD2	87	2	90	91	119	118	0.000		
155-	CQUAD2	88	2	91	92	120	119	0.000		
156-	CQUAD2	89	2	92	93	121	120	0.000		
157-	CQUAD2	90	2	93	94	122	121	0.000		
158-	CQUAD2	91	2	94	95	123	122	0.000		
159-	CQUAD2	92	3	95	96	124	123	0.000		
160-	CQUAD2	93	3	96	97	125	124	0.000		
161-	CQUAD2	94	3	97	98	126	125	0.000		
162-	CQUAD2	95	3	98	99	127	126	0.000		
163-	CQUAD2	96	3	99	100	128	127	0.000		
164-	CQUAD2	97	3	100	101	129	128	0.000		
165-	CQUAD2	98	3	101	102	130	129	0.000		
166-	CQUAD2	99	3	102	103	131	130	0.000		
167-	CQUAD2	100	3	103	104	132	131	0.000		
168-	CQUAD2	101	4	104	105	133	132	0.000		
169-	CQUAD2	102	4	105	106	134	133	0.000		
170-	CQUAD2	103	4	106	107	135	134	0.000		
171-	CQUAD2	104	4	107	108	136	135	0.000		
172-	CQUAD2	105	4	108	109	137	136	0.000		
173-	CQUAD2	106	4	109	110	138	137	0.000		
174-	CQUAD2	107	4	110	111	139	138	0.000		
175-	CQUAD2	108	4	111	112	140	139	0.000		
176-	CQUAD2	109	1	113	114	142	141	0.000		
177-	CQUAD2	110	1	114	115	143	142	0.000		
178-	CQUAD2	111	2	115	116	144	143	0.000		
179-	CQUAD2	112	2	116	117	145	144	0.000		
180-	CQUAD2	113	2	117	118	146	145	0.000		
181-	CQUAD2	114	2	118	119	147	146	0.000		
182-	CQUAD2	115	2	119	120	148	147	0.000		
183-	CQUAD2	116	2	120	121	149	148	0.000		
184-	CQUAD2	117	2	121	122	150	149	0.000		
185-	CQUAD2	118	2	122	123	151	150	0.000		
186-	CQUAD2	119	3	123	124	152	151	0.000		
187-	CQUAD2	120	3	124	125	153	152	0.000		
188-	CQUAD2	121	3	125	126	154	153	0.000		
189-	CQUAD2	122	3	126	127	155	154	0.000		
190-	CQUAD2	123	3	127	128	156	155	0.000		
191-	CQUAD2	124	3	128	129	157	156	0.000		
192-	CQUAD2	125	3	129	130	158	157	0.000		
193-	CQUAD2	126	3	130	131	159	158	0.000		
194-	CQUAD2	127	3	131	132	160	159	0.000		
195-	CQUAD2	128	4	132	133	161	160	0.000		
196-	CQUAD2	129	4	133	134	162	161	0.000		
197-	CQUAD2	130	4	134	135	163	162	0.000		
198-	CQUAD2	131	4	135	136	164	163	0.000		
199-	CQUAD2	132	4	136	137	165	164	0.000		
200-	CQUAD2	133	4	137	138	166	165	0.000		

K.P.SCHWARTZ, 60% SIZE #7D (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS DECEMBER 22, 1976 NASTRAN 9/16/74 PAGE 7

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
201-	CQUAD2	134	4	138	139	167	166	0.000		
202-	CQUAD2	135	4	139	140	168	167	0.000		
203-	CQUAD2	136	1	141	142	170	169	0.000		
204-	CQUAD2	137	1	142	143	171	170	0.000		
205-	CQUAD2	138	2	143	144	172	171	0.000		
206-	CQUAD2	139	2	144	145	173	172	0.000		
207-	CQUAD2	140	2	145	146	174	173	0.000		
208-	CQUAD2	141	2	146	147	175	174	0.000		
209-	CQUAD2	142	2	147	148	176	175	0.000		
210-	CQUAD2	143	2	148	149	177	176	0.000		
211-	CQUAD2	144	2	149	150	178	177	0.000		
212-	CQUAD2	145	2	150	151	179	178	0.000		
213-	CQUAD2	146	3	151	152	180	179	0.000		
214-	CQUAD2	147	3	152	153	181	180	0.000		
215-	CQUAD2	148	3	153	154	182	181	0.000		
216-	CQUAD2	149	3	154	155	183	182	0.000		
217-	CQUAD2	150	3	155	156	184	183	0.000		
218-	CQUAD2	151	3	156	157	185	184	0.000		
219-	CQUAD2	152	3	157	158	186	185	0.000		
220-	CQUAD2	153	3	158	159	187	186	0.000		
221-	CQUAD2	154	3	159	160	188	187	0.000		
222-	CQUAD2	155	4	160	161	189	188	0.000		
223-	CQUAD2	156	4	161	162	190	189	0.000		
224-	CQUAD2	157	4	162	163	191	190	0.000		
225-	CQUAD2	158	4	163	164	192	191	0.000		
226-	CQUAD2	159	4	164	165	193	192	0.000		
227-	CQUAD2	160	4	165	166	194	193	0.000		
228-	CQUAD2	161	4	166	167	195	194	0.000		
229-	CQUAD2	162	4	167	168	196	195	0.000		
230-	CQUAD2	163	1	169	170	198	197	0.000		
231-	CQUAD2	164	1	170	171	199	198	0.000		
232-	CQUAD2	165	2	171	172	200	199	0.000		
233-	CQUAD2	166	2	172	173	201	200	0.000		
234-	CQUAD2	167	2	173	174	202	201	0.000		
235-	CQUAD2	168	2	174	175	203	202	0.000		
236-	CQUAD2	169	2	175	176	204	203	0.000		
237-	CQUAD2	170	2	176	177	205	204	0.000		
238-	CQUAD2	171	2	177	178	206	205	0.000		
239-	CQUAD2	172	2	178	179	207	206	0.000		
240-	CQUAD2	173	3	179	180	208	207	0.000		
241-	CQUAD2	174	3	180	181	209	208	0.000		
242-	CQUAD2	175	3	181	182	210	209	0.000		
243-	CQUAD2	176	3	182	183	211	210	0.000		
244-	CQUAD2	177	3	183	184	212	211	0.000		
245-	CQUAD2	178	3	184	185	213	212	0.000		
246-	CQUAD2	179	3	185	186	214	213	0.000		
247-	CQUAD2	180	3	186	187	215	214	0.000		
248-	CQUAD2	181	3	187	188	216	215	0.000		
249-	CQUAD2	182	4	188	189	217	216	0.000		
250-	CQUAD2	183	4	189	190	218	217	0.000		

K.P.SCHWARTZ, 60% SIZE #7D (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS   DECEMBER 22, 1976   NASTRAN 9/16/74   PAGE 8

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
251-	CQUAD2	184	4	190	191	219	218	0.000		
252-	CQUAD2	185	4	191	192	220	219	0.000		
253-	CQUAD2	186	4	192	193	221	220	0.000		
254-	CQUAD2	187	4	193	194	222	221	0.000		
255-	CQUAD2	188	4	194	195	223	222	0.000		
256-	CQUAD2	189	4	195	196	224	223	0.000		
257-	CQUAD2	190	1	197	198	226	225	0.000		
258-	CQUAD2	191	1	198	199	227	226	0.000		
259-	CQUAD2	192	2	199	200	228	227	0.000		
260-	CQUAD2	193	2	200	201	229	228	0.000		
261-	CQUAD2	194	2	201	202	230	229	0.000		
262-	CQUAD2	135	2	202	203	231	230	0.000		
263-	CQUAD2	196	2	203	204	232	231	0.000		
264-	CQUAD2	197	2	204	205	233	232	0.000		
265-	CQUAD2	138	2	205	206	234	233	0.000		
266-	CQUAD2	199	2	206	207	235	234	0.000		
267-	CQUAD2	200	3	207	208	236	235	0.000		
268-	CQUAD2	201	3	208	209	237	236	0.000		
269-	CQUAD2	202	3	209	210	238	237	0.000		
270-	CQUAD2	203	3	210	211	239	238	0.000		
271-	CQUAD2	204	3	211	212	240	239	0.000		
272-	CQUAD2	205	3	212	213	241	240	0.000		
273-	CQUAD2	206	3	213	214	242	241	0.000		
274-	CQUAD2	207	3	214	215	243	242	0.000		
275-	CQUAD2	208	3	215	216	244	243	0.000		
276-	CQUAD2	209	4	216	217	245	244	0.000		
277-	CQUAD2	210	4	217	218	246	245	0.000		
278-	CQUAD2	211	4	218	219	247	246	0.000		
279-	CQUAD2	212	4	219	220	248	247	0.000		
280-	CQUAD2	213	4	220	221	249	248	0.000		
281-	CQUAD2	214	4	221	222	250	249	0.000		
282-	CQUAD2	215	4	222	223	251	250	0.000		
283-	CQUAD2	216	4	223	224	252	251	0.000		
284-	CQUAD2	217	1	225	226	254	253	0.000		
285-	CQUAD2	218	1	226	227	255	254	0.000		
286-	CQUAD2	219	2	227	228	256	255	0.000		
287-	CQUAD2	220	2	228	229	257	256	0.000		
288-	CQUAD2	221	2	229	230	258	257	0.000		
289-	CQUAD2	222	2	230	231	259	258	0.000		
290-	CQUAD2	223	2	231	232	260	259	0.000		
291-	CQUAD2	224	2	232	233	261	260	0.000		
292-	CQUAD2	225	2	233	234	262	261	0.000		
293-	CQUAD2	226	2	234	235	263	262	0.000		
294-	CQUAD2	227	3	235	236	264	263	0.000		
295-	CQUAD2	228	3	236	237	265	264	0.000		
296-	CQUAD2	229	3	237	238	266	265	0.000		
297-	CQUAD2	230	3	238	239	267	266	0.000		
298-	CQUAD2	231	3	239	240	268	267	0.000		
299-	CQUAD2	232	3	240	241	269	268	0.000		
300-	CQUAD2	233	3	241	242	270	269	0.000		

K.P.SCHWARTZ, 60% SIZE #70 (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS DECEMBER 22, 1976 NASTRAN 9/16/74 PAGE 9

SORTED BULK DATA ECHO

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
301-	CQUAD2	234	3	242	243	271	270	0.000		
302-	CQUAD2	235	3	243	244	272	271	0.000		
303-	CQUAD2	236	4	244	245	273	272	0.000		
304-	CQUAD2	237	4	245	246	274	273	0.000		
305-	CQUAD2	238	4	246	247	275	274	0.000		
306-	CQUAD2	239	4	247	248	276	275	0.000		
307-	CQUAD2	240	4	248	249	277	276	0.000		
308-	CQUAD2	241	4	249	250	278	277	0.000		
309-	CQUAD2	242	4	250	251	279	278	0.000		
310-	CQUAD2	243	4	251	252	280	279	0.000		
311-	CQUAD2	244	1	253	254	282	281	0.000		
312-	CQUAD2	245	1	254	255	283	282	0.000		
313-	CQUAD2	246	2	255	256	284	283	0.000		
314-	CQUAD2	247	2	256	257	285	284	0.000		
315-	CQUAD2	248	2	257	258	286	285	0.000		
316-	CQUAD2	249	2	258	259	287	286	0.000		
317-	CQUAD2	250	2	259	260	288	287	0.000		
318-	CQUAD2	251	2	260	261	289	288	0.000		
319-	CQUAD2	252	2	261	262	290	289	0.000		
320-	CQUAD2	253	2	262	263	291	290	0.000		
321-	CQUAD2	254	3	263	264	292	291	0.000		
322-	CQUAD2	255	3	264	265	293	292	0.000		
323-	CQUAD2	256	3	265	266	294	293	0.000		
324-	CQUAD2	257	3	266	267	295	294	0.000		
325-	CQUAD2	258	3	267	268	296	295	0.000		
326-	CQUAD2	259	3	268	269	297	296	0.000		
327-	CQUAD2	260	3	269	270	298	297	0.000		
328-	CQUAD2	261	3	270	271	299	298	0.000		
329-	CQUAD2	262	3	271	272	300	299	0.000		
330-	CQUAD2	263	4	272	273	301	300	0.000		
331-	CQUAD2	264	4	273	274	302	301	0.000		
332-	CQUAD2	265	4	274	275	303	302	0.000		
333-	CQUAD2	266	4	275	276	304	303	0.000		
334-	CQUAD2	267	4	276	277	305	304	0.000		
335-	CQUAD2	268	4	277	278	306	305	0.000		
336-	CQUAD2	269	4	278	279	307	306	0.000		
337-	CQUAD2	270	4	279	280	308	307	0.000		
338-	CQUAD2	271	1	281	282	310	309	0.000		
339-	CQUAD2	272	1	282	283	311	310	0.000		
340-	CQUAD2	273	2	283	284	312	311	0.000		
341-	CQUAD2	274	2	284	285	313	312	0.000		
342-	CQUAD2	275	2	285	286	314	313	0.000		
343-	CQUAD2	276	2	286	287	315	314	0.000		
344-	CQUAD2	277	2	287	288	316	315	0.000		
345-	CQUAD2	278	2	288	289	317	316	0.000		
346-	CQUAD2	279	2	289	290	318	317	0.000		
347-	CQUAD2	280	2	290	291	319	318	0.000		
348-	CQUAD2	281	3	291	292	320	319	0.000		
349-	CQUAD2	282	3	292	293	321	320	0.000		
350-	CQUAD2	283	3	293	294	322	321	0.000		

K.P.SCHWARTZ, 60% SIZE #7D (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS DECEMBER 22, 1976 NASTRAN 9/16/74 PAGE 10

S O R T E D B U L K D A T A E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 .. 10 .
351-	CQUAD2	284	3	294	295	323	322	0.000	
352-	CQUAD2	285	3	295	296	324	323	0.000	
353-	CQUAD2	286	3	296	297	325	324	0.000	
354-	CQUAD2	287	3	297	298	326	325	0.000	
355-	CQUAD2	288	3	298	299	327	326	0.000	
356-	CQUAD2	289	3	299	300	328	327	0.000	
357-	CQUAD2	290	4	300	301	329	328	0.000	
358-	CQUAD2	291	4	301	302	330	329	0.000	
359-	CQUAD2	292	4	302	303	331	330	0.000	
360-	CQUAD2	293	4	303	304	332	331	0.000	
361-	CQUAD2	294	4	304	305	333	332	0.000	
362-	CQUAD2	295	4	305	306	334	333	0.000	
363-	CQUAD2	296	4	306	307	335	334	0.000	
364-	CQUAD2	297	4	307	308	336	335	0.000	
365-	CQUAD2	298	1	309	310	338	337	0.000	
366-	CQUAD2	299	1	310	311	339	338	0.000	
367-	CQUAD2	300	2	311	312	340	339	0.000	
368-	CQUAD2	301	2	312	313	341	340	0.000	
369-	CQUAD2	302	2	313	314	342	341	0.000	
370-	CQUAD2	303	2	314	315	343	342	0.000	
371-	CQUAD2	304	2	315	316	344	343	0.000	
372-	CQUAD2	305	2	316	317	345	344	0.000	
373-	CQUAD2	306	2	317	318	346	345	0.000	
374-	CQUAD2	307	2	318	319	347	346	0.000	
375-	CQUAD2	308	3	319	320	348	347	0.000	
376-	CQUAD2	309	3	320	321	349	348	0.000	
377-	CQUAD2	310	3	321	322	350	349	0.000	
378-	CQUAD2	311	3	322	323	351	350	0.000	
379-	CQUAD2	312	3	323	324	352	351	0.000	
380-	CQUAD2	313	3	324	325	353	352	0.000	
381-	CQUAD2	314	3	325	326	354	353	0.000	
382-	CQUAD2	315	3	326	327	355	354	0.000	
383-	CQUAD2	316	3	327	328	356	355	0.000	
384-	CQUAD2	317	4	328	329	357	356	0.000	
385-	CQUAD2	318	4	329	330	358	357	0.000	
386-	CQUAD2	319	4	330	331	359	358	0.000	
387-	CQUAD2	320	4	331	332	360	359	0.000	
388-	CQUAD2	321	4	332	333	361	360	0.000	
389-	CQUAD2	322	4	333	334	362	361	0.000	
390-	CQUAD2	323	4	334	335	363	362	0.000	
391-	CQUAD2	324	4	335	336	364	363	0.000	
392-	CQUAD2	325	1	337	338	366	365	0.000	
393-	CQUAD2	326	1	338	339	367	366	0.000	
394-	CQUAD2	327	2	339	340	368	367	0.000	
395-	CQUAD2	328	2	340	341	369	368	0.000	
396-	CQUAD2	329	2	341	342	370	369	0.000	
397-	CQUAD2	330	2	342	343	371	370	0.000	
398-	CQUAD2	331	2	343	344	372	371	0.000	
399-	CQUAD2	332	2	344	345	373	372	0.000	
400-	CQUAD2	333	2	345	346	374	373	0.000	

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 .. 10 .
401-	CQUAD2 334	2	346	347	375	374	0.000		
402-	CQUAD2 335	3	347	348	376	375	0.000		
403-	CQUAD2 336	3	348	349	377	376	0.000		
404-	CQUAD2 337	3	349	350	378	377	0.000		
405-	CQUAD2 338	3	350	351	379	378	0.000		
406-	CQUAD2 339	3	351	352	380	379	0.000		
407-	CQUAD2 340	3	352	353	381	380	0.000		
408-	CQUAD2 341	3	353	354	382	381	0.000		
409-	CQUAD2 342	3	354	355	383	382	0.000		
410-	CQUAD2 343	3	355	356	384	383	0.000		
411-	CQUAD2 344	4	356	357	385	384	0.000		
412-	CQUAD2 345	4	357	358	386	385	0.000		
413-	CQUAD2 346	4	358	359	387	386	0.000		
414-	CQUAD2 347	4	359	360	388	387	0.000		
415-	CQUAD2 348	4	360	361	389	388	0.000		
416-	CQUAD2 349	4	361	362	390	389	0.000		
417-	CQUAD2 350	4	362	363	391	390	0.000		
418-	CQUAD2 351	4	363	364	392	391	0.000		
419-	CQUAD2 352	1	365	366	394	393	0.000		
420-	CQUAD2 353	1	366	367	395	394	0.000		
421-	CQUAD2 354	2	367	368	396	395	0.000		
422-	CQUAD2 355	2	368	369	397	396	0.000		
423-	CQUAD2 356	2	369	370	398	397	0.000		
424-	CQUAD2 357	2	370	371	399	398	0.000		
425-	CQUAD2 358	2	371	372	400	399	0.000		
426-	CQUAD2 359	2	372	373	401	400	0.000		
427-	CQUAD2 360	2	373	374	402	401	0.000		
428-	CQUAD2 361	2	374	375	403	402	0.000		
429-	CQUAD2 362	3	375	376	404	403	0.000		
430-	CQUAD2 363	3	376	377	405	404	0.000		
431-	CQUAD2 364	3	377	378	406	405	0.000		
432-	CQUAD2 365	3	378	379	407	406	0.000		
433-	CQUAD2 366	3	379	380	408	407	0.000		
434-	CQUAD2 367	3	380	381	409	408	0.000		
435-	CQUAD2 368	3	381	382	410	409	0.000		
436-	CQUAD2 369	3	382	383	411	410	0.000		
437-	CQUAD2 370	3	383	384	412	411	0.000		
438-	CQUAD2 371	4	384	385	413	412	0.000		
439-	CQUAD2 372	4	385	386	414	413	0.000		
440-	CQUAD2 373	4	386	387	415	414	0.000		
441-	CQUAD2 374	4	387	388	416	415	0.000		
442-	CQUAD2 375	4	388	389	417	416	0.000		
443-	CQUAD2 376	4	389	390	418	417	0.000		
444-	CQUAD2 377	4	390	391	419	418	0.000		
445-	CQUAD2 378	4	391	392	420	419	0.000		
446-	CQUAD2 379	1	393	394	422	421	0.000		
447-	CQUAD2 380	1	394	395	423	422	0.000		
448-	CQUAD2 381	2	395	396	424	423	0.000		
449-	CQUAD2 382	2	396	397	425	424	0.000		
450-	CQUAD2 383	2	397	398	426	425	0.000		

K.P.SCHWARTZ, 60% SIZE #70 (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS DECEMBER 22, 1976 NASTRAN 9/16/74 PAGE 12

S O R T E D B U L K D A T A E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
451-	CQUAD2	384	2	398	399	427	426	0.000		
452-	CQUAD2	385	2	399	400	428	427	0.000		
453-	CQUAD2	386	2	400	401	429	428	0.000		
454-	CQUAD2	387	2	401	402	430	429	0.000		
455-	CQUAD2	388	2	402	403	431	430	0.000		
456-	CQUAD2	389	3	403	404	432	431	0.000		
457-	CQUAD2	390	3	404	405	433	432	0.000		
458-	CQUAD2	391	3	405	406	434	433	0.000		
459-	CQUAD2	392	3	406	407	435	434	0.000		
460-	CQUAD2	393	3	407	408	436	435	0.000		
461-	CQUAD2	394	3	408	409	437	436	0.000		
462-	CQUAD2	395	3	409	410	438	437	0.000		
463-	CQUAD2	396	3	410	411	439	438	0.000		
464-	CQUAD2	397	3	411	412	440	439	0.000		
465-	CQUAD2	398	4	412	413	441	440	0.000		
466-	CQUAD2	399	4	413	414	442	441	0.000		
467-	CQUAD2	400	4	414	415	443	442	0.000		
468-	CQUAD2	401	4	415	416	444	443	0.000		
469-	CQUAD2	402	4	416	417	445	444	0.000		
470-	CQUAD2	403	4	417	418	446	445	0.000		
471-	CQUAD2	404	4	418	419	447	446	0.000		
472-	CQUAD2	405	4	419	420	448	447	0.000		
473-	CQUAD2	406	1	421	422	450	449	0.000		
474-	CQUAD2	407	1	422	423	451	450	0.000		
475-	CQUAD2	408	2	423	424	452	451	0.000		
476-	CQUAD2	409	2	424	425	453	452	0.000		
477-	CQUAD2	410	2	425	426	454	453	0.000		
478-	CQUAD2	411	2	426	427	455	454	0.000		
479-	CQUAD2	412	2	427	428	456	455	0.000		
480-	CQUAD2	413	2	428	429	457	456	0.000		
481-	CQUAD2	414	2	429	430	458	457	0.000		
482-	CQUAD2	415	2	430	431	459	458	0.000		
483-	CQUAD2	416	3	431	432	460	459	0.000		
484-	CQUAD2	417	3	432	433	461	460	0.000		
485-	CQUAD2	418	3	433	434	462	461	0.000		
486-	CQUAD2	419	3	434	435	463	462	0.000		
487-	CQUAD2	420	3	435	436	464	463	0.000		
488-	CQUAD2	421	3	436	437	465	464	0.000		
489-	CQUAD2	422	3	437	438	466	465	0.000		
490-	CQUAD2	423	3	438	439	467	466	0.000		
491-	CQUAD2	424	3	439	440	468	467	0.000		
492-	CQUAD2	425	4	440	441	469	468	0.000		
493-	CQUAD2	426	4	441	442	470	469	0.000		
494-	CQUAD2	427	4	442	443	471	470	0.000		
495-	CQUAD2	428	4	443	444	472	471	0.000		
496-	CQUAD2	429	4	444	445	473	472	0.000		
497-	CQUAD2	430	4	445	446	474	473	0.000		
498-	CQUAD2	431	4	446	447	475	474	0.000		
499-	CQUAD2	432	4	447	448	476	475	0.000		
500-	GRAV	*21				.0360000E+07		.0000		QGRAV1

K.P.SCHWARTZ, 60% SIZE #7D (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS DECEMBER 22, 1976 NASTRAN 9/16/74 PAGE 13

S O R T E D B U L K D A T A E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
501-	+GRAV1	-1.0000	0.0000							
502-	GRID	1		.00	.00	.00				
503-	GRID	2		.07	.00	.00				
504-	GRID	3		.15	.00	.00				
505-	GRID	4		.20	.00	.00				
506-	GRID	5		.30	.00	.00				
507-	GRID	6		.40	.00	.00				
508-	GRID	7		.45	.00	.00				
509-	GRID	8		.50	.00	.00				
510-	GRID	9		.55	.00	.00				
511-	GRID	10		.60	.00	.00				
512-	GRID	11		.65	.00	.00				
513-	GRID	12		.75	.00	.00				
514-	GRID	13		.85	.00	.00				
515-	GRID	14		.95	.00	.00				
516-	GRID	15		1.05	.00	.00				
517-	GRID	16		1.15	.00	.00				
518-	GRID	17		1.30	.00	.00				
519-	GRID	18		1.50	.00	.00				
520-	GRID	19		1.75	.00	.00				
521-	GRID	20		2.00	.00	.00				
522-	GRID	21		2.25	.00	.00				
523-	GRID	22		2.50	.00	.00				
524-	GRID	23		2.75	.00	.00				
525-	GRID	24		3.00	.00	.00				
526-	GRID	25		3.25	.00	.00				
527-	GRID	26		3.50	.00	.00				
528-	GRID	27		3.75	.00	.00				
529-	GRID	28		4.00	.00	.00				
530-	GRID	29		.00	.17	.00				
531-	GRID	30		.07	.17	.00				
532-	GRID	31		.15	.17	.00				
533-	GRID	32		.20	.17	.00				
534-	GRID	33		.30	.17	.00				
535-	GRID	34		.40	.17	.00				
536-	GRID	35		.45	.17	.00				
537-	GRID	36		.50	.17	.00				
538-	GRID	37		.55	.17	.00				
539-	GRID	38		.60	.17	.00				
540-	GRID	39		.65	.17	.00				
541-	GRID	40		.75	.17	.00				
542-	GRID	41		.85	.17	.00				
543-	GRID	42		.95	.17	.00				
544-	GRID	43		1.05	.17	.00				
545-	GRID	44		1.15	.17	.00				
546-	GRID	45		1.30	.17	.00				
547-	GRID	46		1.50	.17	.00				
548-	GRID	47		1.75	.17	.00				
549-	GRID	48		2.00	.17	.00				
550-	GRID	49		2.25	.17	.00				

K.P.SCHWARTZ, 60% SIZE #7D (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS   DECEMBER 22, 1976   NASTRAN 9/16/74   PAGE   14

SORTED BULK DATA ECHO

CARD COUNT	1	2	3	4	5	6	7	8	9	10
551-	GRID	50		2.50	.17	.00				
552-	GRID	51		2.75	.17	.00				
553-	GRID	52		3.00	.17	.00				
554-	GRID	53		3.25	.17	.00				
555-	GRID	54		3.50	.17	.00				
556-	GRID	55		3.75	.17	.00				
557-	GRID	56		4.00	.17	.00				
558-	GRID	57		.00	.20	.00				
559-	GRID	58		.07	.20	.00				
560-	GRID	59		.15	.20	.00				
561-	GRID	60		.20	.20	.00				
562-	GRID	61		.30	.20	.00				
563-	GRID	62		.40	.20	.00				
564-	GRID	63		.45	.20	.00				
565-	GRID	64		.50	.20	.00				
566-	GRID	65		.55	.20	.00				
567-	GRID	66		.60	.20	.00				
568-	GRID	67		.65	.20	.00				
569-	GRID	68		.75	.20	.00				
570-	GRID	69		.85	.20	.00				
571-	GRID	70		.95	.20	.00				
572-	GRID	71		1.05	.20	.00				
573-	GRID	72		1.15	.20	.00				
574-	GRID	73		1.30	.20	.00				
575-	GRID	74		1.50	.20	.00				
576-	GRID	75		1.75	.20	.00				
577-	GRID	76		2.00	.20	.00				
578-	GRID	77		2.25	.20	.00				
579-	GRID	78		2.50	.20	.00				
580-	GRID	79		2.75	.20	.00				
581-	GRID	80		3.00	.20	.00				
582-	GRID	81		3.25	.20	.00				
583-	GRID	82		3.50	.20	.00				
584-	GRID	83		3.75	.20	.00				
585-	GRID	84		4.00	.20	.00				
586-	GRID	85		.00	.40	.00				
587-	GRID	86		.07	.40	.00				
588-	GRID	87		.15	.40	.00				
589-	GRID	88		.20	.40	.00				
590-	GRID	89		.30	.40	.00				
591-	GRID	90		.40	.40	.00				
592-	GRID	91		.45	.40	.00				
593-	GRID	92		.50	.40	.00				
594-	GRID	93		.55	.40	.00				
595-	GRID	94		.60	.40	.00				
596-	GRID	95		.65	.40	.00				
597-	GRID	96		.75	.40	.00				
598-	GRID	97		.85	.40	.00				
599-	GRID	98		.95	.40	.00				
600-	GRID	99		1.05	.40	.00				

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K.P.SCHWARTZ, 60% SIZE #7D ( 0 DEG.=3,+45,-45,90 DEG.  LAYERS ) AS     DECEMBER  22, 1976   NASTRAN  9/16/74    PAGE    15

                                        S O R T E D   B U L K   D A T A   E C H O
 CARD
 COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
  601-        GRID    100             1.15    .40     .00
  602-        GRID    101             1.30    .40     .00
  603-        GRID    102             1.50    .40     .00
  604-        GRID    103             1.75    .40     .00
  605-        GRID    104             2.00    .40     .00
  606-        GRID    105             2.25    .40     .00
  607-        GRID    106             2.50    .40     .00
  608-        GRID    107             2.75    .40     .00
  609-        GRID    108             3.00    .40     .00
  610-        GRID    109             3.25    .40     .00
  611-        GRID    110             3.50    .40     .00
  612-        GRID    111             3.75    .40     .00
  613-        GRID    112             4.00    .40     .00
  614-        GRID    113             .00     .60     .00
  615-        GRID    114             .07     .60     .00
  616-        GRID    115             .15     .60     .00
  617-        GRID    116             .20     .60     .00
  618-        GRID    117             .30     .60     .00
  619-        GRID    118             .40     .60     .00
  620-        GRID    119             .45     .60     .00
  621-        GRID    120             .50     .60     .00
  622-        GRID    121             .55     .60     .00
  623-        GRID    122             .60     .60     .00
  624-        GRID    123             .65     .60     .00
  625-        GRID    124             .75     .60     .00
  626-        GRID    125             .85     .60     .00
  627-        GRID    126             .95     .60     .00
  628-        GRID    127             1.05    .60     .00
  629-        GRID    128             1.15    .60     .00
  630-        GRID    129             1.30    .60     .00
  631-        GRID    130             1.50    .60     .00
  632-        GRID    131             1.75    .60     .00
  633-        GRID    132             2.00    .60     .00
  634-        GRID    133             2.25    .60     .00
  635-        GRID    134             2.50    .60     .00
  636-        GRID    135             2.75    .60     .00
  637-        GRID    136             3.00    .60     .00
  638-        GRID    137             3.25    .60     .00
  639-        GRID    138             3.50    .60     .00
  640-        GRID    139             3.75    .60     .00
  641-        GRID    140             4.00    .60     .00
  642-        GRID    141             .00     .80     .00
  643-        GRID    142             .07     .80     .00
  644-        GRID    143             .15     .80     .00
  645-        GRID    144             .20     .80     .00
  646-        GRID    145             .30     .80     .00
  647-        GRID    146             .40     .80     .00
  648-        GRID    147             .45     .80     .00
  649-        GRID    148             .50     .80     .00
  650-        GRID    149             .55     .80     .00
```

K.P.SCHWARTZ, 60% SIZE #7D (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS   DECEMBER 22, 1976   NASTRAN 9/16/74   PAGE 16

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 .. 7 .. 8 .. 9 .. 10 .
651-	GRID	150	.60	.80	.00	
652-	GRID	151	.65	.80	.00	
653-	GRID	152	.75	.80	.00	
654-	GRID	153	.85	.80	.00	
655-	GRID	154	.95	.80	.00	
656-	GRID	155	1.05	.80	.00	
657-	GRID	156	1.15	.80	.00	
658-	GRID	157	1.30	.80	.00	
659-	GRID	158	1.50	.80	.00	
660-	GRID	159	1.75	.80	.00	
661-	GRID	160	2.00	.80	.00	
662-	GRID	161	2.25	.80	.00	
663-	GRID	162	2.50	.80	.00	
664-	GRID	163	2.75	.80	.00	
665-	GRID	164	3.00	.80	.00	
666-	GRID	165	3.25	.80	.00	
667-	GRID	166	3.50	.80	.00	
668-	GRID	167	3.75	.80	.00	
669-	GRID	168	4.00	.80	.00	
670-	GRID	169	.00	1.00	.00	
671-	GRID	170	.07	1.00	.00	
672-	GRID	171	.15	1.00	.00	
673-	GRID	172	.20	1.00	.00	
674-	GRID	173	.30	1.00	.00	
675-	GRID	174	.40	1.00	.00	
676-	GRID	175	.45	1.00	.00	
677-	GRID	176	.50	1.00	.00	
678-	GRID	177	.55	1.00	.00	
679-	GRID	178	.60	1.00	.00	
680-	GRID	179	.65	1.00	.00	
681-	GRID	180	.75	1.00	.00	
682-	GRID	181	.85	1.00	.00	
683-	GRID	182	.95	1.00	.00	
684-	GRID	183	1.05	1.00	.00	
685-	GRID	184	1.15	1.00	.00	
686-	GRID	185	1.30	1.00	.00	
687-	GRID	186	1.50	1.00	.00	
688-	GRID	187	1.75	1.00	.00	
689-	GRID	188	2.00	1.00	.00	
690-	GRID	189	2.25	1.00	.00	
691-	GRID	190	2.50	1.00	.00	
692-	GRID	191	2.75	1.00	.00	
693-	GRID	192	3.00	1.00	.00	
694-	GRID	193	3.25	1.00	.00	
695-	GRID	194	3.50	1.00	.00	
696-	GRID	195	3.75	1.00	.00	
697-	GRID	196	4.00	1.00	.00	
698-	GRID	197	.00	1.20	.00	
699-	GRID	198	.07	1.20	.00	
700-	GRID	199	.15	1.20	.00	

K.P.SCHWARTZ, 60% SIZE #7D (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS   DECEMBER 22, 1976   NASTRAN 9/16/74   PAGE 17

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 .. 7 .. 8 .. 9 .. 10 .
701-	GRID	200		.20	1.20	.00
702-	GRID	201		.30	1.20	.00
703-	GRID	202		.40	1.20	.00
704-	GRID	203		.45	1.20	.00
705-	GRID	204		.50	1.20	.00
706-	GRID	205		.55	1.20	.00
707-	GRID	206		.60	1.20	.00
708-	GRID	207		.65	1.20	.00
709-	GRID	208		.75	1.20	.00
710-	GRID	209		.85	1.20	.00
711-	GRID	210		.95	1.20	.00
712-	GRID	211		1.05	1.20	.00
713-	GRID	212		1.15	1.20	.00
714-	GRID	213		1.30	1.20	.00
715-	GRID	214		1.50	1.20	.00
716-	GRID	215		1.75	1.20	.00
717-	GRID	216		2.00	1.20	.00
718-	GRID	217		2.25	1.20	.00
719-	GRID	218		2.50	1.20	.00
720-	GRID	219		2.75	1.20	.00
721-	GRID	220		3.00	1.20	.00
722-	GRID	221		3.25	1.20	.00
723-	GRID	222		3.50	1.20	.00
724-	GRID	223		3.75	1.20	.00
725-	GRID	224		4.00	1.20	.00
726-	GRID	225		.00	1.40	.00
727-	GRID	226		.07	1.40	.00
728-	GRID	227		.15	1.40	.00
729-	GRID	228		.20	1.40	.00
730-	GRID	229		.30	1.40	.00
731-	GRID	230		.40	1.40	.00
732-	GRID	231		.45	1.40	.00
733-	GRID	232		.50	1.40	.00
734-	GRID	233		.55	1.40	.00
735-	GRID	234		.60	1.40	.00
736-	GRID	235		.65	1.40	.00
737-	GRID	236		.75	1.40	.00
738-	GRID	237		.85	1.40	.00
739-	GRID	238		.95	1.40	.00
740-	GRID	239		1.05	1.40	.00
741-	GRID	240		1.15	1.40	.00
742-	GRID	241		1.30	1.40	.00
743-	GRID	242		1.50	1.40	.00
744-	GRID	243		1.75	1.40	.00
745-	GRID	244		2.00	1.40	.00
746-	GRID	245		2.25	1.40	.00
747-	GRID	246		2.50	1.40	.00
748-	GRID	247		2.75	1.40	.00
749-	GRID	248		3.00	1.40	.00
750-	GRID	249		3.25	1.40	.00

K.P.SCHWARTZ, 60% SIZE #7D (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS DECEMBER 22, 1976 NASTRAN 9/16/74 PAGE 18

S O R T E D B U L K D A T A E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
751-	GRID	250		3.50	1.40	.00				
752-	GRID	251		3.75	1.40	.00				
753-	GRID	252		4.00	1.40	.00				
754-	GRID	253		.00	1.60	.00				
755-	GRID	254		.07	1.60	.00				
756-	GRID	255		.15	1.60	.00				
757-	GRID	256		.20	1.60	.00				
758-	GRID	257		.30	1.60	.00				
759-	GRID	258		.40	1.60	.00				
760-	GRID	259		.45	1.60	.00				
761-	GRID	260		.50	1.60	.00				
762-	GRID	261		.55	1.60	.00				
763-	GRID	262		.60	1.60	.00				
764-	GRID	263		.65	1.60	.00				
765-	GRID	264		.75	1.60	.00				
766-	GRID	265		.85	1.60	.00				
767-	GRID	266		.95	1.60	.00				
768-	GRID	267		1.05	1.60	.00				
769-	GRID	268		1.15	1.60	.00				
770-	GRID	269		1.30	1.60	.00				
771-	GRID	270		1.50	1.60	.00				
772-	GRID	271		1.75	1.60	.00				
773-	GRID	272		2.00	1.60	.00				
774-	GRID	273		2.25	1.60	.00				
775-	GRID	274		2.50	1.60	.00				
776-	GRID	275		2.75	1.60	.00				
777-	GRID	276		3.00	1.60	.00				
778-	GRID	277		3.25	1.60	.00				
779-	GRID	278		3.50	1.60	.00				
780-	GRID	279		3.75	1.60	.00				
781-	GRID	280		4.00	1.60	.00				
782-	GRID	281		.00	1.80	.00				
783-	GRID	282		.07	1.80	.00				
784-	GRID	283		.15	1.80	.00				
785-	GRID	284		.20	1.80	.00				
786-	GRID	285		.30	1.80	.00				
787-	GRID	286		.40	1.80	.00				
788-	GRID	287		.45	1.80	.00				
789-	GRID	288		.50	1.80	.00				
790-	GRID	289		.55	1.80	.00				
791-	GRID	290		.60	1.80	.00				
792-	GRID	291		.65	1.80	.00				
793-	GRID	292		.75	1.80	.00				
794-	GRID	293		.85	1.80	.00				
795-	GRID	294		.95	1.80	.00				
796-	GRID	295		1.05	1.80	.00				
797-	GRID	296		1.15	1.80	.00				
798-	GRID	297		1.30	1.80	.00				
799-	GRID	298		1.50	1.80	.00				
800-	GRID	299		1.75	1.80	.00				

K.P.SCHWARTZ, 60% SIZE #7D (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS DECEMBER 22, 1976 NASTRAN 9/16/74 PAGE 19

S O R T E D B U L K D A T A E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
801-	GRID	300		2.00	1.80	.00				
802-	GRID	301		2.25	1.80	.00				
803-	GRID	302		2.50	1.80	.00				
804-	GRID	303		2.75	1.80	.00				
805-	GRID	304		3.00	1.80	.00				
806-	GRID	305		3.25	1.80	.00				
807-	GRID	306		3.50	1.80	.00				
808-	GRID	307		3.75	1.80	.00				
809-	GRID	308		4.00	1.80	.00				
810-	GRID	309		.00	2.00	.00				
811-	GRID	310		.07	2.00	.00				
812-	GRID	311		.15	2.00	.00				
813-	GRID	312		.20	2.00	.00				
814-	GRID	313		.30	2.00	.00				
815-	GRID	314		.40	2.00	.00				
816-	GRID	315		.45	2.00	.00				
817-	GRID	316		.50	2.00	.00				
818-	GRID	317		.55	2.00	.00				
819-	GRID	318		.60	2.00	.00				
820-	GRID	319		.65	2.00	.00				
821-	GRID	320		.75	2.00	.00				
822-	GRID	321		.85	2.00	.00				
823-	GRID	322		.95	2.00	.00				
824-	GRID	323		1.05	2.00	.00				
825-	GRID	324		1.15	2.00	.00				
826-	GRID	325		1.30	2.00	.00				
827-	GRID	326		1.50	2.00	.00				
828-	GRID	327		1.75	2.00	.00				
829-	GRID	328		2.00	2.00	.00				
830-	GRID	329		2.25	2.00	.00				
831-	GRID	330		2.50	2.00	.00				
832-	GRID	331		2.75	2.00	.00				
833-	GRID	332		3.00	2.00	.00				
834-	GRID	333		3.25	2.00	.00				
835-	GRID	334		3.50	2.00	.00				
836-	GRID	335		3.75	2.00	.00				
837-	GRID	336		4.00	2.00	.00				
838-	GRID	337		.00	2.20	.00				
839-	GRID	338		.07	2.20	.00				
840-	GRID	339		.15	2.20	.00				
841-	GRID	340		.20	2.20	.00				
842-	GRID	341		.30	2.20	.00				
843-	GRID	342		.40	2.20	.00				
844-	GRID	343		.45	2.20	.00				
845-	GRID	344		.50	2.20	.00				
846-	GRID	345		.55	2.20	.00				
847-	GRID	346		.60	2.20	.00				
848-	GRID	347		.65	2.20	.00				
849-	GRID	348		.75	2.20	.00				
850-	GRID	349		.85	2.20	.00				

K.P.SCHWARTZ, 60% SIZE #70 (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS DECEMBER 22, 1976 NASTRAN 9/16/74 PAGE 20

S O R T E D B U L K D A T A E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 .. 7 .. 8 .. 9 .. 10 .
851-	GRID	350		.95	2.20	.00
852-	GRID	351		1.05	2.20	.00
853-	GRID	352		1.15	2.20	.00
854-	GRID	353		1.30	2.20	.00
855-	GRID	354		1.50	2.20	.00
856-	GRID	355		1.75	2.20	.00
857-	GRID	356		2.00	2.20	.00
858-	GRID	357		2.25	2.20	.00
859-	GRID	358		2.50	2.20	.00
860-	GRID	359		2.75	2.20	.00
861-	GRID	360		3.00	2.20	.00
862-	GRID	361		3.25	2.20	.00
863-	GRID	362		3.50	2.20	.00
864-	GRID	363		3.75	2.20	.00
865-	GRID	364		4.00	2.20	.00
866-	GRID	365		.00	2.40	.00
867-	GRID	366		.07	2.40	.00
868-	GRID	367		.15	2.40	.00
869-	GRID	368		.20	2.40	.00
870-	GRID	369		.30	2.40	.00
871-	GRID	370		.40	2.40	.00
872-	GRID	371		.45	2.40	.00
873-	GRID	372		.50	2.40	.00
874-	GRID	373		.55	2.40	.00
875-	GRID	374		.60	2.40	.00
876-	GRID	375		.65	2.40	.00
877-	GRID	376		.75	2.40	.00
878-	GRID	377		.85	2.40	.00
879-	GRID	378		.95	2.40	.00
880-	GRID	379		1.05	2.40	.00
881-	GRID	380		1.15	2.40	.00
882-	GRID	381		1.30	2.40	.00
883-	GRID	382		1.50	2.40	.00
884-	GRID	383		1.75	2.40	.00
885-	GRID	384		2.00	2.40	.00
886-	GRID	385		2.25	2.40	.00
887-	GRID	386		2.50	2.40	.00
888-	GRID	387		2.75	2.40	.00
889-	GRID	388		3.00	2.40	.00
890-	GRID	389		3.25	2.40	.00
891-	GRID	390		3.50	2.40	.00
892-	GRID	391		3.75	2.40	.00
893-	GRID	392		4.00	2.40	.00
894-	GRID	393		.00	2.60	.00
895-	GRID	394		.07	2.60	.00
896-	GRID	395		.15	2.60	.00
897-	GRID	396		.20	2.60	.00
898-	GRID	397		.30	2.60	.00
899-	GRID	398		.40	2.60	.00
900-	GRID	399		.45	2.60	.00

K.P.SCHWARTZ, 60% SIZE #7D (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS DECEMBER 22, 1976 NASTRAN 9/16/74 PAGE 21

SORTED BULK DATA ECHO

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
901-	GRID	400		.50	2.60	.00				
902-	GRID	401		.55	2.60	.00				
903-	GRID	402		.60	2.60	.00				
904-	GRID	403		.65	2.60	.00				
905-	GRID	404		.75	2.60	.00				
906-	GRID	405		.85	2.60	.00				
907-	GRID	406		.95	2.60	.00				
908-	GRID	407		1.05	2.60	.00				
909-	GRID	408		1.15	2.60	.00				
910-	GRID	409		1.30	2.60	.00				
911-	GRID	410		1.50	2.60	.00				
912-	GRID	411		1.75	2.60	.00				
913-	GRID	412		2.00	2.60	.00				
914-	GRID	413		2.25	2.60	.00				
915-	GRID	414		2.50	2.60	.00				
916-	GRID	415		2.75	2.60	.00				
917-	GRID	416		3.00	2.60	.00				
918-	GRID	417		3.25	2.60	.00				
919-	GRID	418		3.50	2.60	.00				
920-	GRID	419		3.75	2.60	.00				
921-	GRID	420		4.00	2.60	.00				
922-	GRID	421		.00	2.70	.00				
923-	GRID	422		.07	2.70	.00				
924-	GRID	423		.15	2.70	.00				
925-	GRID	424		.20	2.70	.00				
926-	GRID	425		.30	2.70	.00				
927-	GRID	426		.40	2.70	.00				
928-	GRID	427		.45	2.70	.00				
929-	GRID	428		.50	2.70	.00				
930-	GRID	429		.55	2.70	.00				
931-	GRID	430		.60	2.70	.00				
932-	GRID	431		.65	2.70	.00				
933-	GRID	432		.75	2.70	.00				
934-	GRID	433		.85	2.70	.00				
935-	GRID	434		.95	2.70	.00				
936-	GRID	435		1.05	2.70	.00				
937-	GRID	436		1.15	2.70	.00				
938-	GRID	437		1.30	2.70	.00				
939-	GRID	438		1.50	2.70	.00				
940-	GRID	439		1.75	2.70	.00				
941-	GRID	440		2.00	2.70	.00				
942-	GRID	441		2.25	2.70	.00				
943-	GRID	442		2.50	2.70	.00				
944-	GRID	443		2.75	2.70	.00				
945-	GRID	444		3.00	2.70	.00				
946-	GRID	445		3.25	2.70	.00				
947-	GRID	446		3.50	2.70	.00				
948-	GRID	447		3.75	2.70	.00				
949-	GRID	448		4.00	2.70	.00				
950-	GRID	449		.00	2.83	.00				

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K.P.SCHWARTZ, 60% SIZE #7D ( 0 DEG.=3,+45,-45,90 DEG.  LAYERS ) AS     DECEMBER  22, 1976   NASTRAN  9/16/74    PAGE     22

                              S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT        .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
  951-        GRID    450              .07     2.83    .00
  952-        GRID    451              .15     2.83    .00
  953-        GRID    452              .20     2.83    .00
  954-        GRID    453              .30     2.83    .00
  955-        GRID    454              .40     2.83    .00
  956-        GRID    455              .45     2.83    .00
  957-        GRID    456              .50     2.83    .00
  958-        GRID    457              .55     2.83    .00
  959-        GRID    458              .60     2.83    .00
  960-        GRID    459              .65     2.83    .00
  961-        GRID    460              .75     2.83    .00
  962-        GRID    461              .85     2.83    .00
  963-        GRID    462              .95     2.83    .00
  964-        GRID    463              1.05    2.83    .00
  965-        GRID    464              1.15    2.83    .00
  966-        GRID    465              1.30    2.83    .00
  967-        GRID    466              1.50    2.83    .00
  968-        GRID    467              1.75    2.83    .00
  969-        GRID    468              2.00    2.83    .00
  970-        GRID    469              2.25    2.83    .00
  971-        GRID    470              2.50    2.83    .00
  972-        GRID    471              2.75    2.83    .00
  973-        GRID    472              3.00    2.83    .00
  974-        GRID    473              3.25    2.83    .00
  975-        GRID    474              3.50    2.83    .00
  976-        GRID    475              3.75    2.83    .00
  977-        GRID    476              4.00    2.83    .00
  978-        GRID    477              -.90    2.00    .00
  979-        GRID    478              -.72    2.00    .00
  980-        GRID    479              -.54    2.00    .00
  981-        GRID    480              -.36    2.00    .00
  982-        GRID    481              -.18    2.00    .00
  983-        GRID    482              0.000   5.500   0.000
  984-        LOAD    30      1.0000   1.0000  20      1.0000  21
  985-        MAT1    5       3.0E7            .3200   .2800
  986-        MAT1    6       3.0E7            .3200   .2800
  987-        MAT1    7       3.0E0            .3200   .0001
  988-        MAT1    8       3.0E0            .3200   .0001
  989-        MAT2    1       12.98+6  1.97+6          6.53+6          2.27+6  .056
  990-        MAT2    2       12.98+6  1.97+6          6.53+6          2.27+6  .056
  991-        MAT2    3       12.98+6  1.97+6          6.53+6          2.27+6  .056
  992-        MAT2    4       12.98+6  1.97+6          6.53+6          2.27+6  .056
  993-        PARAM   GRDPNT  0
  994-        PARAM   WTMASS  .002588
  995-        PBAR    *5               5               .2543637E+00    .1245837E-01    QABCDEF1
  996-        *ABCDEF1    .1245837E-01    .24000
  997-        PBAR    *6               6               .3141593E-01    .7853982E-04    QABCDEF2
  998-        *ABCDEF2    .7853982E-04    .2000000E+00
  999-        PBAR    *7               7               .1410261E-01    .1582665E-04    QABCDEF3
 1000-        *ABCDEF3    .1582665E-04    .1250000E+00
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K.P.SCHWARTZ, 60% SIZE #70 ( 0 DEG.=3,+45,-45,90 DEG.  LAYERS ) AS     DECEMBER  22, 1976   NASTRAN  9/16/74    PAGE     23

                                   S O R T E D   B U L K   D A T A   E C H O
 CARD
 COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
 1001-        PBAR    *8              8                      .7088218E-02      .3998198E-05      QABCDEF4
 1002-        *ABCDEF4      .3998198E-05       .9500000E-01
 1003-        PBAR    3       8       .4415   .0155   .0155   .80000
 1004-        PQUAD2  1       1       .2240
 1005-        PQUAD2  2       2       .2240
 1006-        PQUAD2  3       3       .2240
 1007-        PQUAD2  4       4       .224
 1008-        RFORCE  *20             482
 1009-        +RFORCE1  1.0000   0.0000  0.0000                                 .5166666E+02      QRFORCE1
 1010-        SPC1    100     15      28
 1011-        SPC1    101     15      56
 1012-        SPC1    102     15      84
 1013-        SPC1    103     15      112
 1014-        SPC1    104     15      140
 1015-        SPC1    105     15      168
 1016-        SPC1    106     15      196
 1017-        SPC1    107     15      224
 1018-        SPC1    108     15      252
 1019-        SPC1    109     15      280
 1020-        SPC1    110     15      308
 1021-        SPC1    111     15      336
 1022-        SPC1    112     15      364
 1023-        SPC1    113     15      392
 1024-        SPC1    114     15      420
 1025-        SPC1    115     15      448
 1026-        SPC1    116     15      476
 1027-        SPC1    500     123456  477     482
 1028-        SPC1    501     6       1       THRU    28
 1029-        SPC1    501     6       57      THRU    224
 1030-        SPC1    501     6       226     THRU    252
 1031-        SPC1    501     6       254     THRU    280
 1032-        SPC1    501     6       282     THRU    308
 1033-        SPC1    501     6       338     THRU    364
 1034-        SPC1    501     6       366     THRU    392
 1035-        SPC1    501     6       394     THRU    476
 1036-        SPC1    502     2       479
 1037-        SPC1    503     2       478     479
 1038-        SPC1    504     2       478     479     480
 1039-        SPC1    505     2       480
 1040-        SPC1    506     2       478     479     480     481
 1041-        SPCADD  90      100     101     102     103     104     105     106     ABC20
 1042-        +BC20   107     108     109     110     111     112     113     114ABC21
 1043-        +BC21   115     116     500     501     502
 1044-        SPCADD  91      100     101     102     103     104     105     106     ABC30
 1045-        +BC30   107     108     109     110     111     112     113     114ABC31
 1046-        +BC31   115     116     500     501     503
 1047-        SPCADD  92      100     101     102     103     104     105     106     ABC40
 1048-        +BC40   107     108     109     110     111     112     113     114ABC41
 1049-        +BC41   115     116     500     501     504
 1050-        SPCADD  93      100     101     102     103     104     105     106     ABC50
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K.P.SCHWARTZ, 60% SIZE #7D ( 0 DEG.=3,+45,-45,90 DEG. LAYERS ) AS     DECEMBER 22, 1976   NASTRAN 9/16/74    PAGE    24

                                 S O R T E D   B U L K   D A T A   E C H O
 CARD
 COUNT        .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10
 1051-        +BC50     107     108     109     110     111     112     113     114ABC51
 1052-        +BC51     115     116     500     501     505
 1053-        SPCADD  94     100     101     102     103     104     105     106     ABC60
 1054-        +BC60     107     108     109     110     111     112     113     114ABC61
 1055-        +BC61     115     116     500     501     506
 1056-        SPCADD  99     100     101     102     103     104     105     106     ABC10
 1057-        +BC10     107     108     109     110     111     112     113     114ABC11
 1058-        +BC11     115     116     500     501     504
              ENDDATA

**NO ERRORS FOUND - EXECUTE NASTRAN PROGRAM**
```
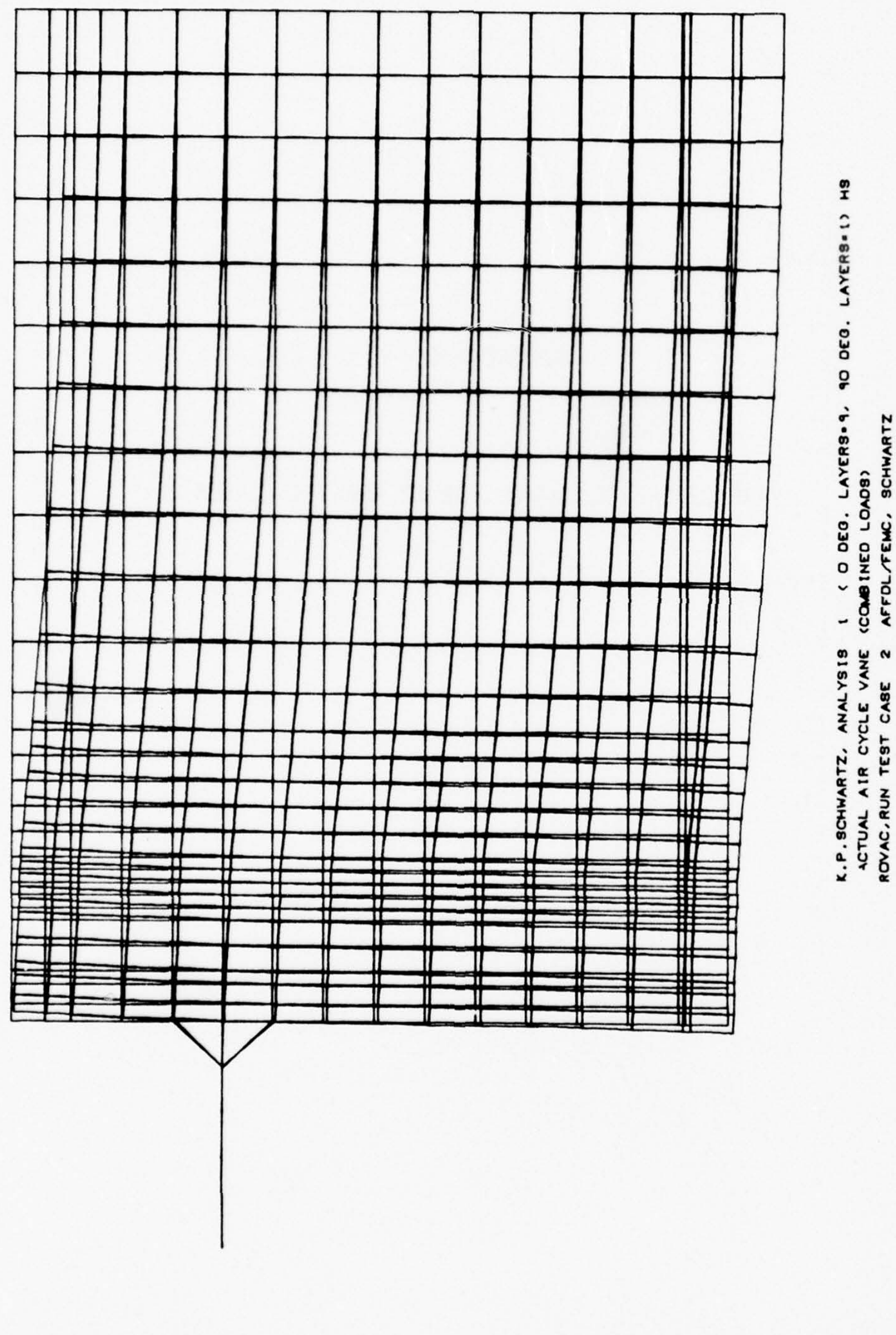
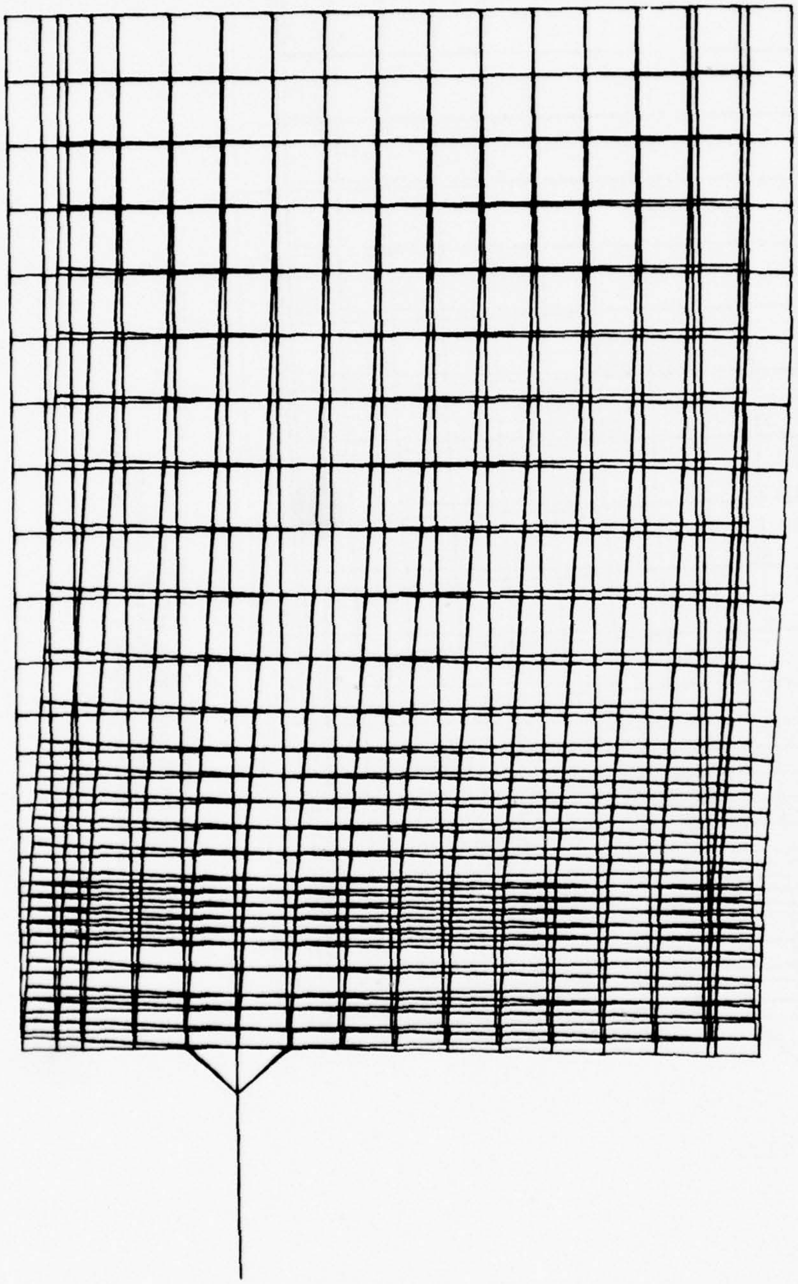
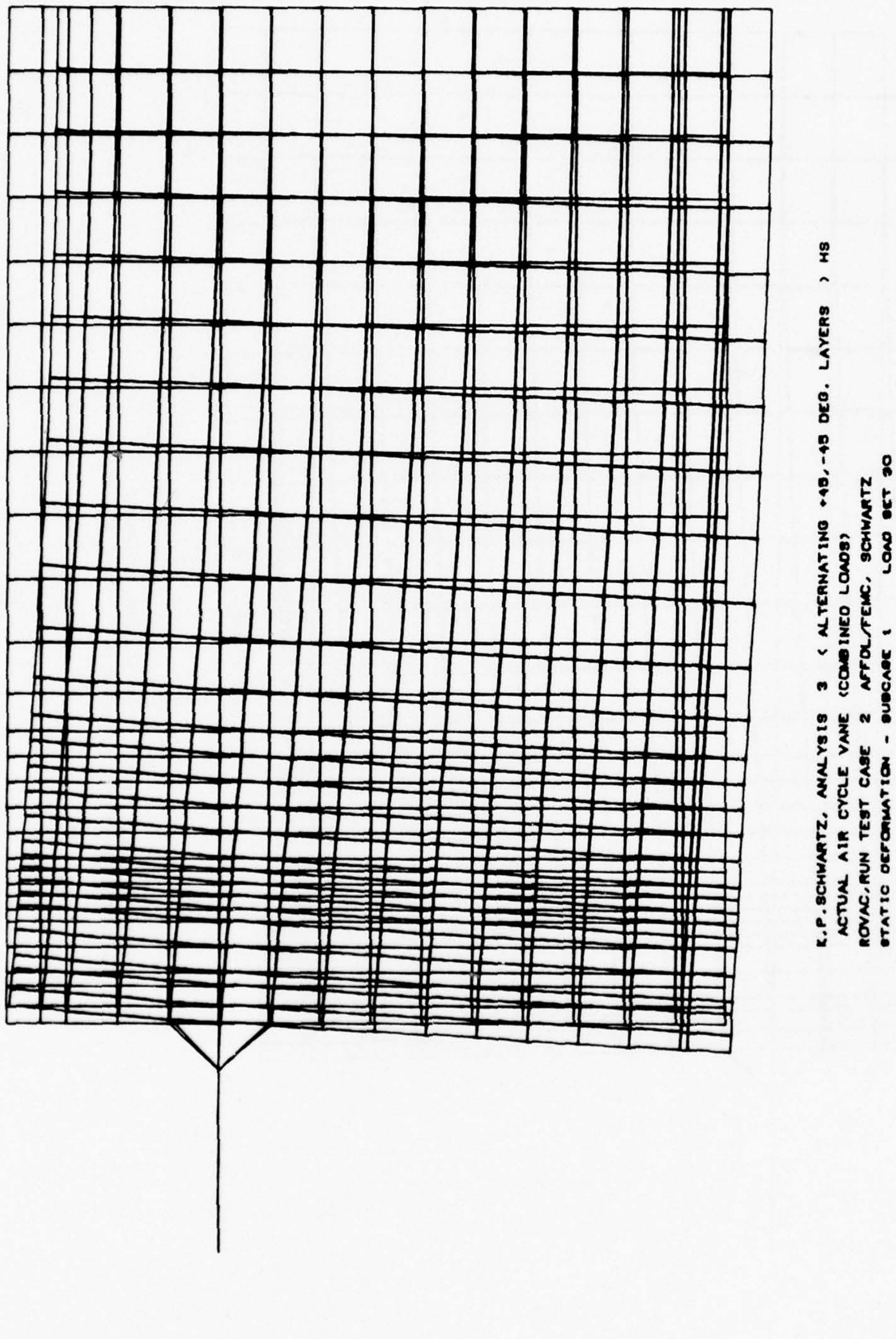

APPENDIX D

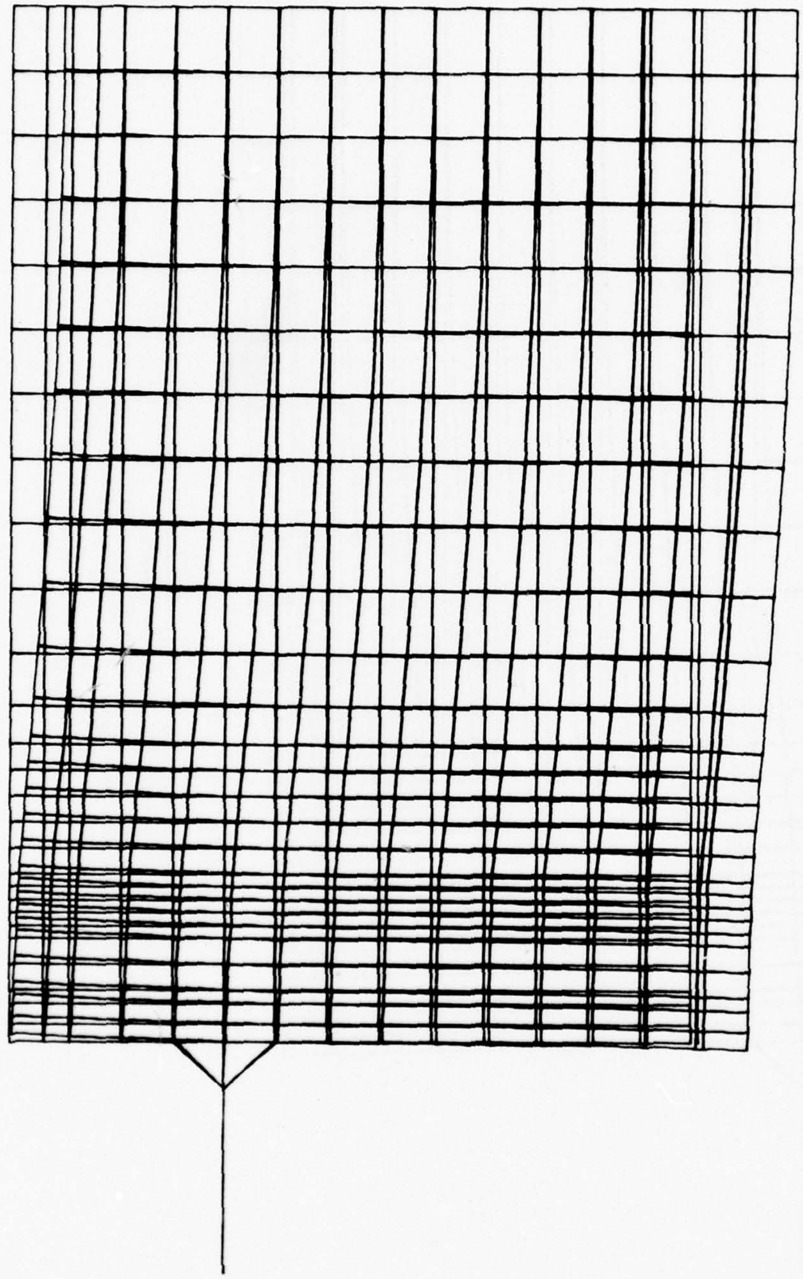
VANE DEFLECTED SHAPES FOR 22 ANALYSIS CASES


K.P.SCHWARTZ, ANALYSIS 1 (0 DEG. LAYERS=9, 90 DEG. LAYERS=1) HS
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC,RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 20

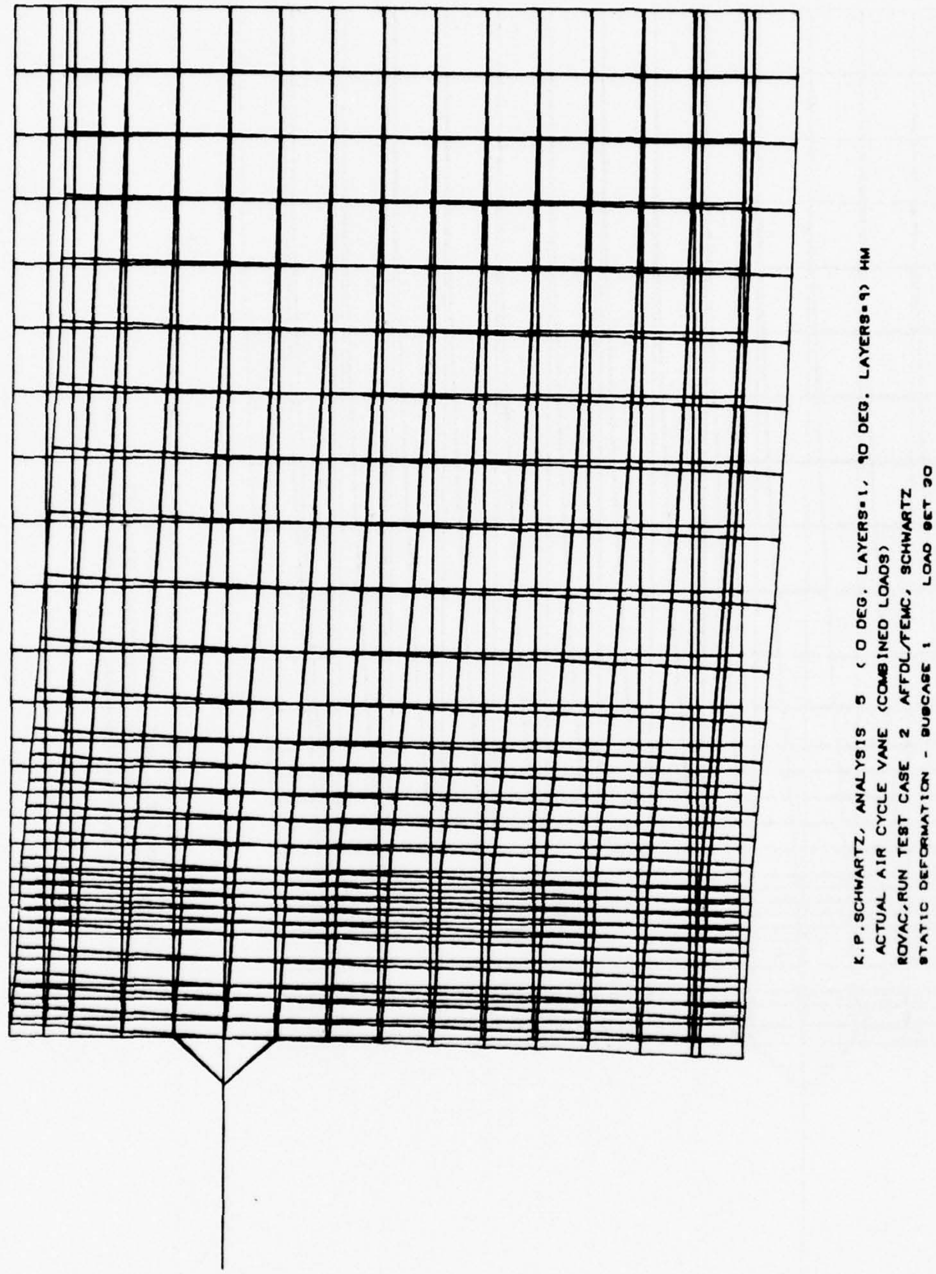

K.P.SCHWARTZ, ANALYSIS 2 (0 DEG. LAYERS=1, 90 DEG. LAYERS=9) HS
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC;RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 30

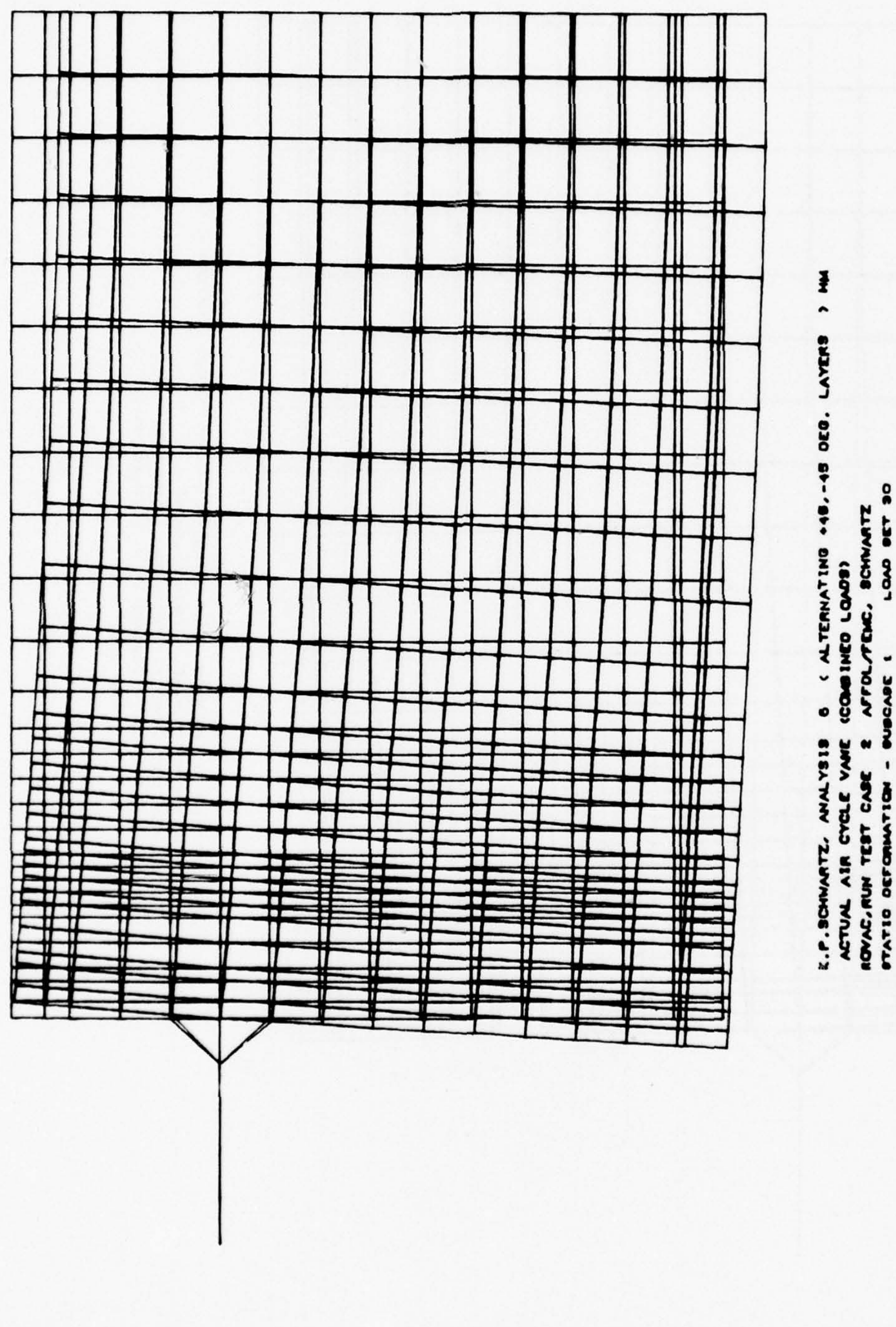


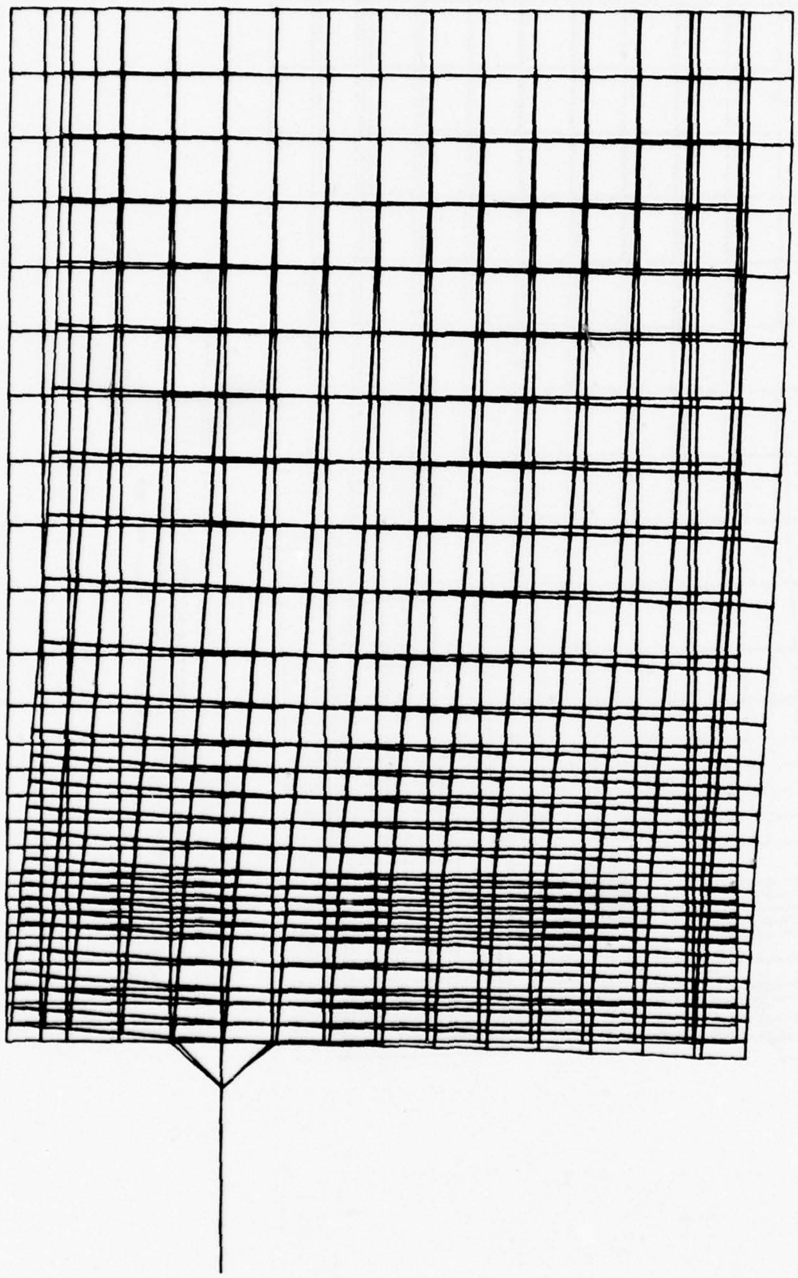
K.P.SCHWARTZ, ANALYSIS 3 (ALTERNATING +45,-45 DEG. LAYERS) HS
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC.RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 30



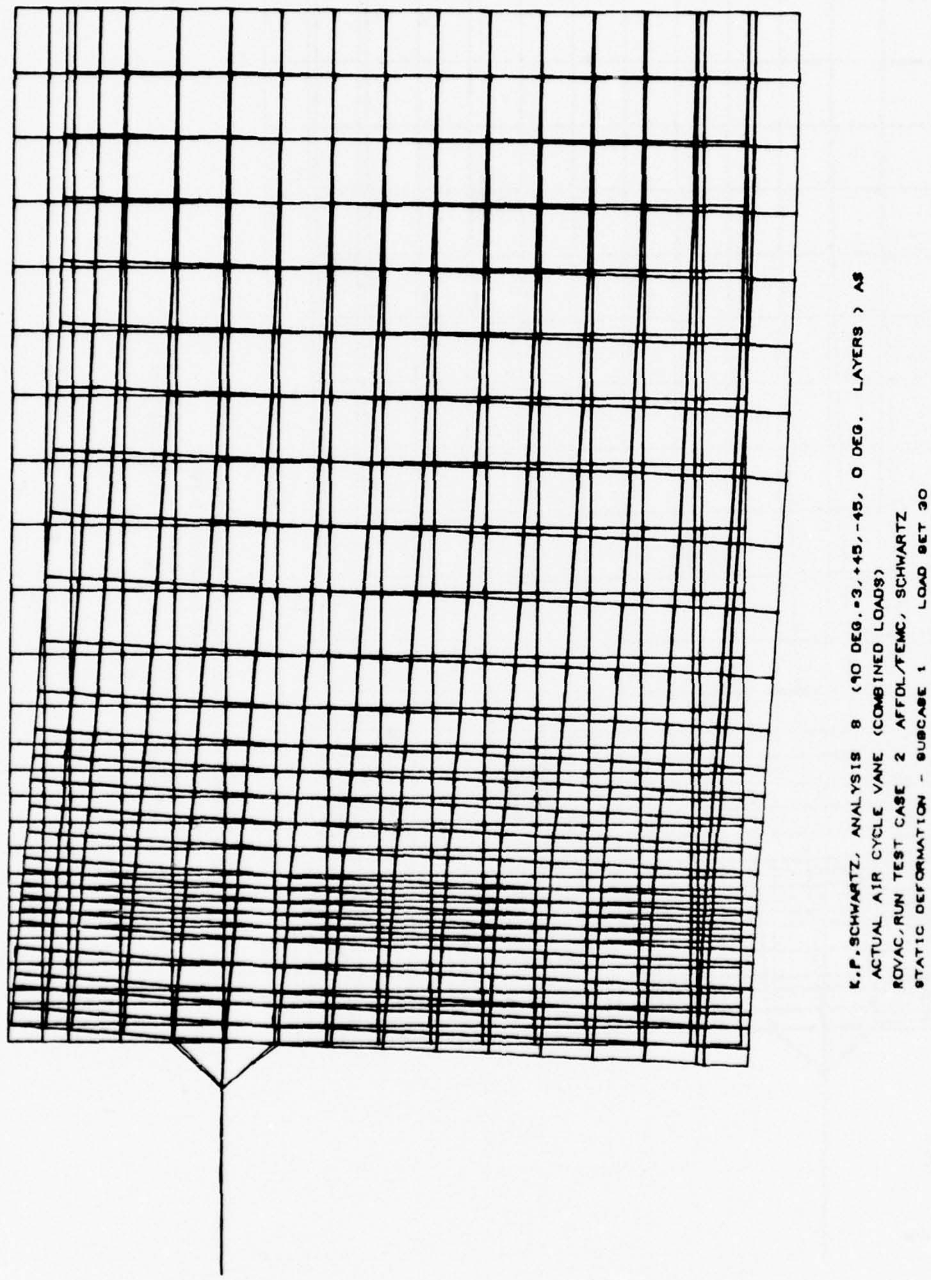
K.P.SCHWARTZ, ANALYSIS 4 (0 DEG. LAYERS=9, 90 DEG. LAYERS=1) HM
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC,RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 30

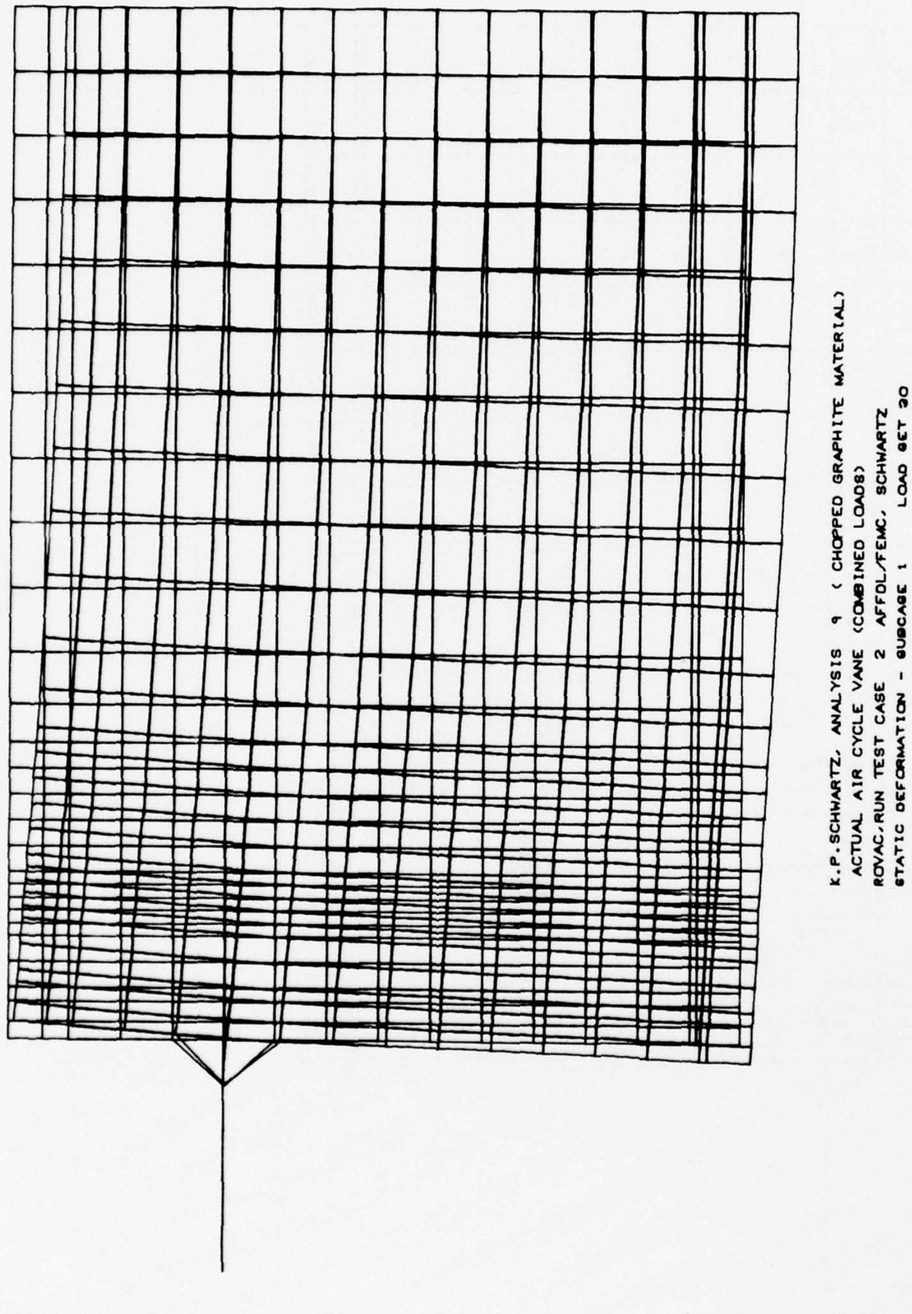

K.P.SCHWARTZ, ANALYSIS 5 (0 DEG. LAYERS=1, 90 DEG. LAYERS=9) HM
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC,RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 30

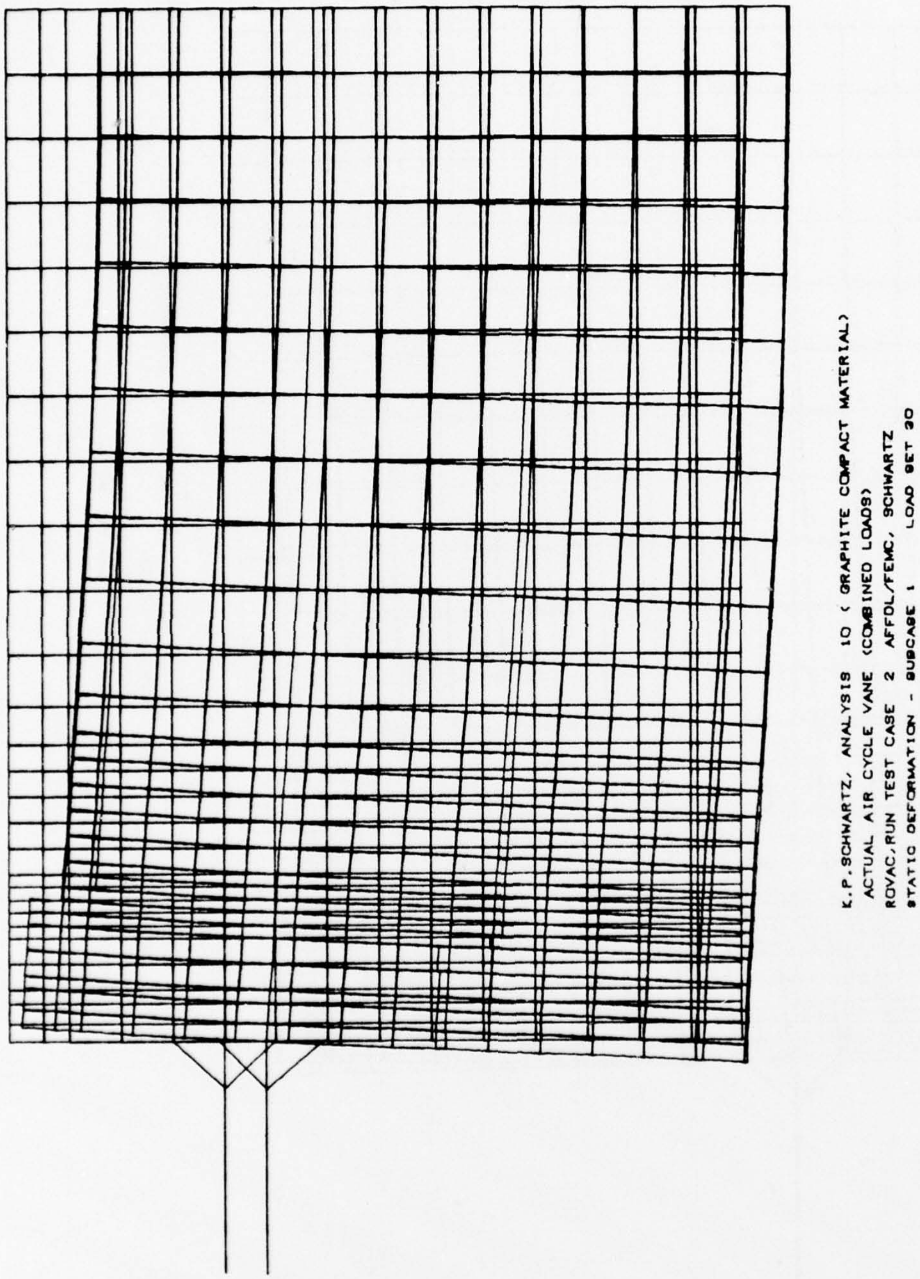

E.P.SCHWARTZ, ANALYSIS 6 (ALTERNATING +45,-45 DEG. LAYERS) MM
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
SOVAC,RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 30

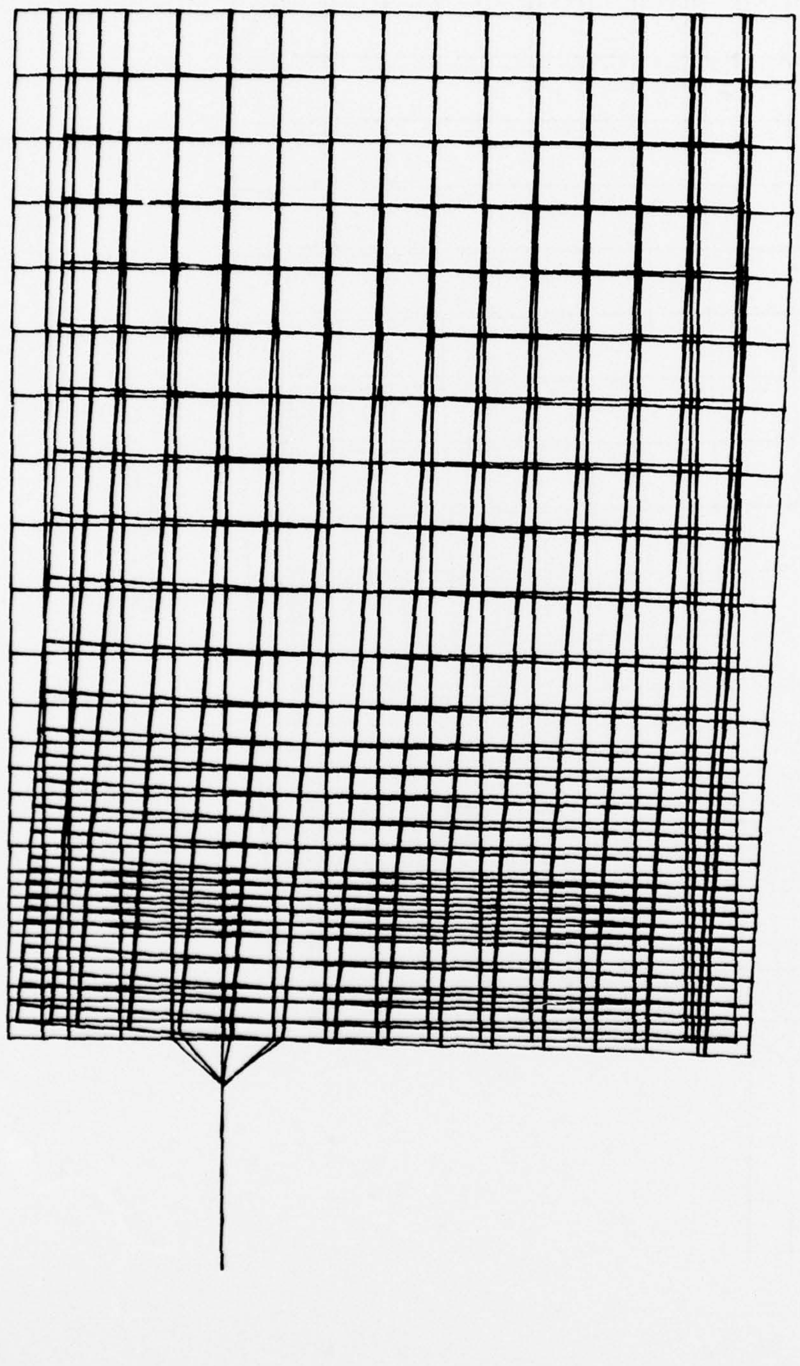


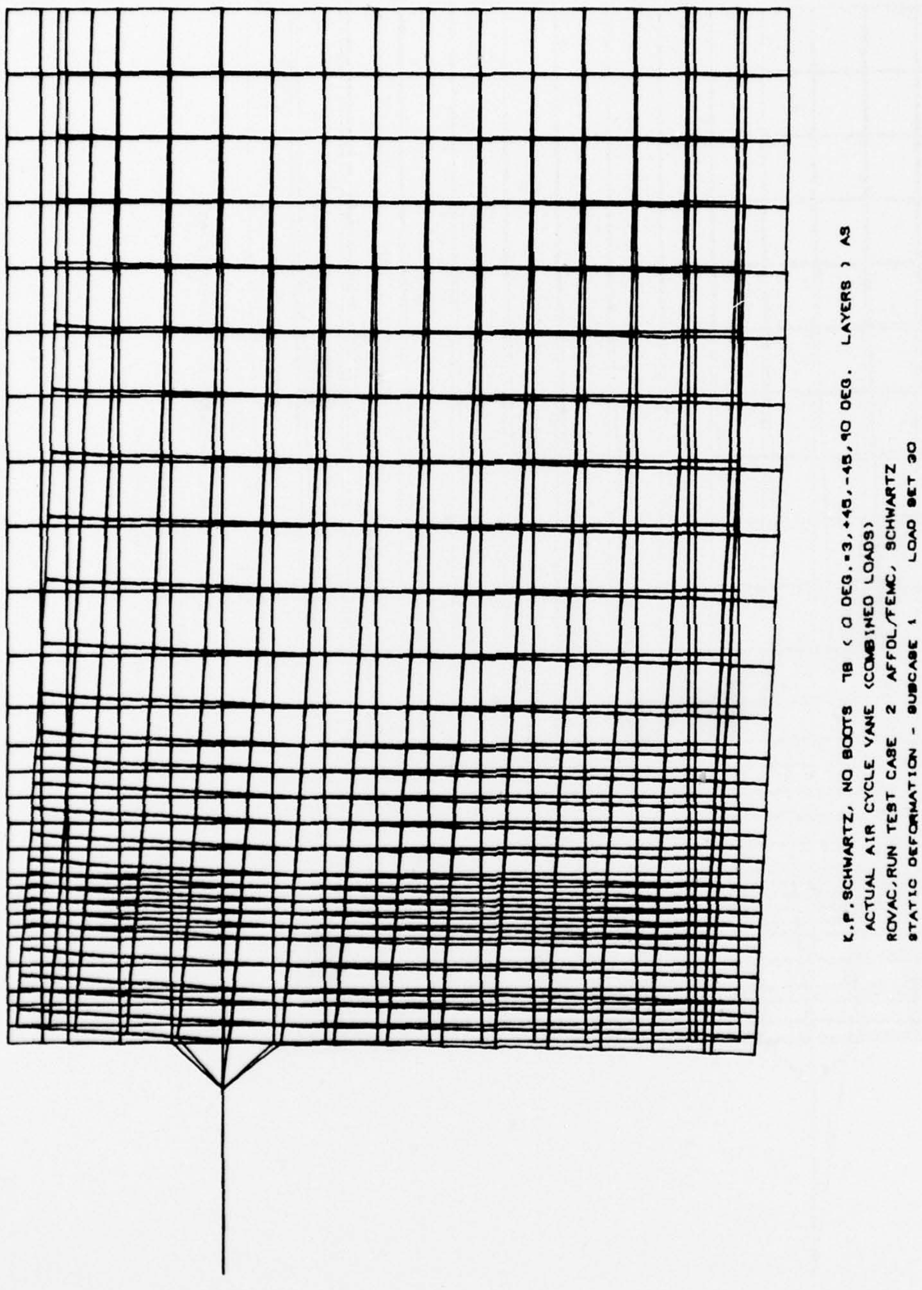
K.P.SCHWARTZ, ANALYSIS 7 (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC,RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 30

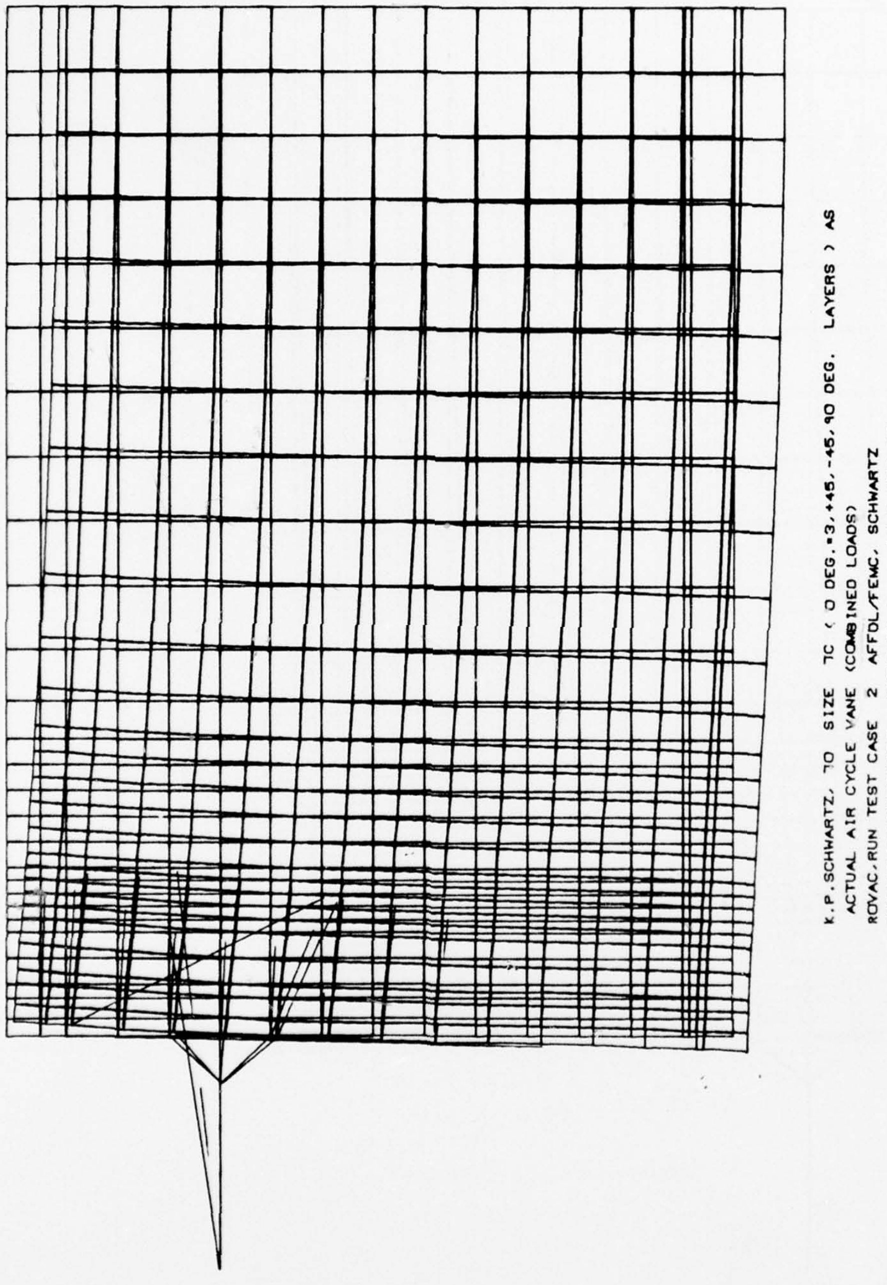

K.P.SCHWARTZ, ANALYSIS 8 (90 DEG.=3,+45,-45, 0 DEG. LAYERS) AS
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC,RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 30

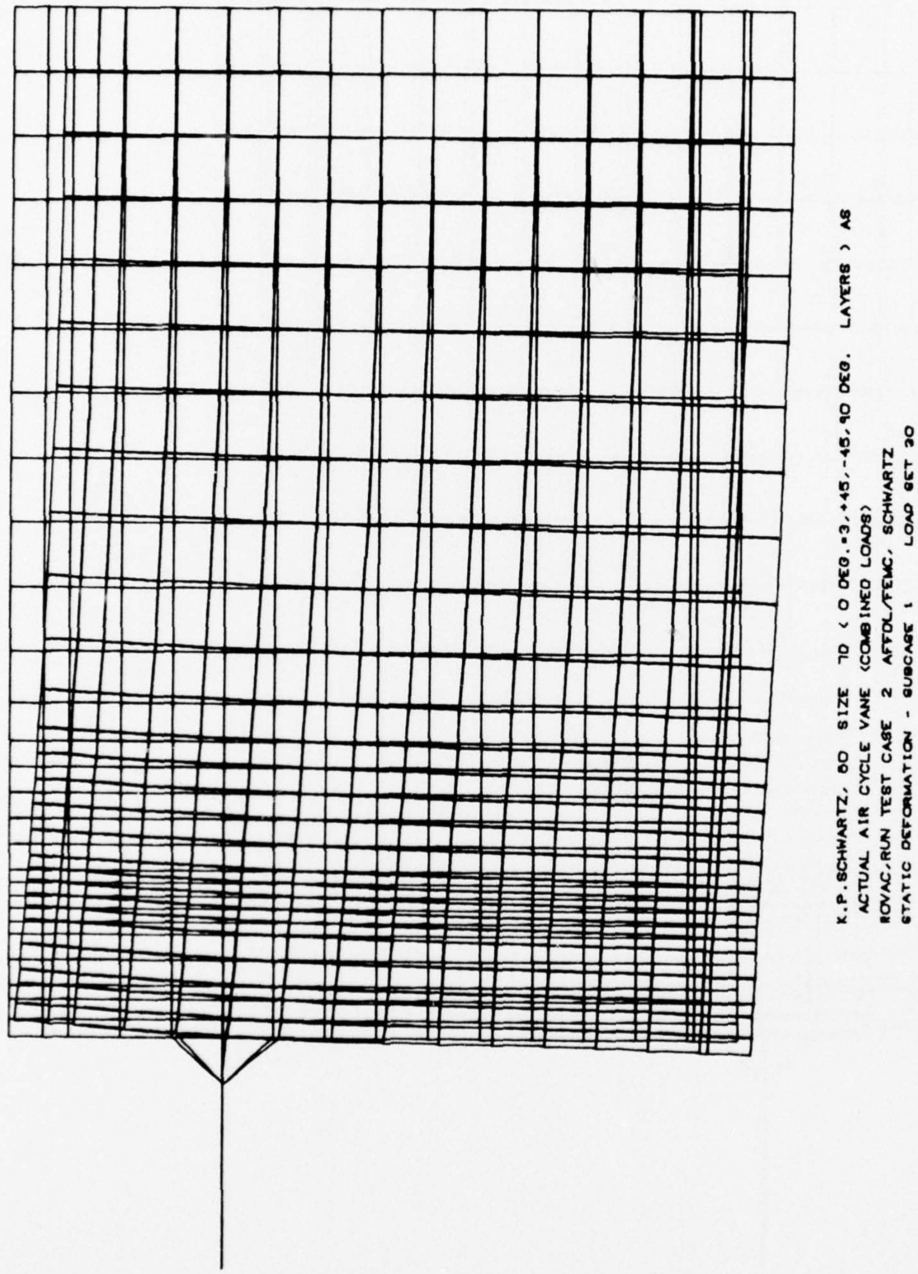

K.P.SCHWARTZ, ANALYSIS 9 (CHOPPED GRAPHITE MATERIAL)
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC,RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 30

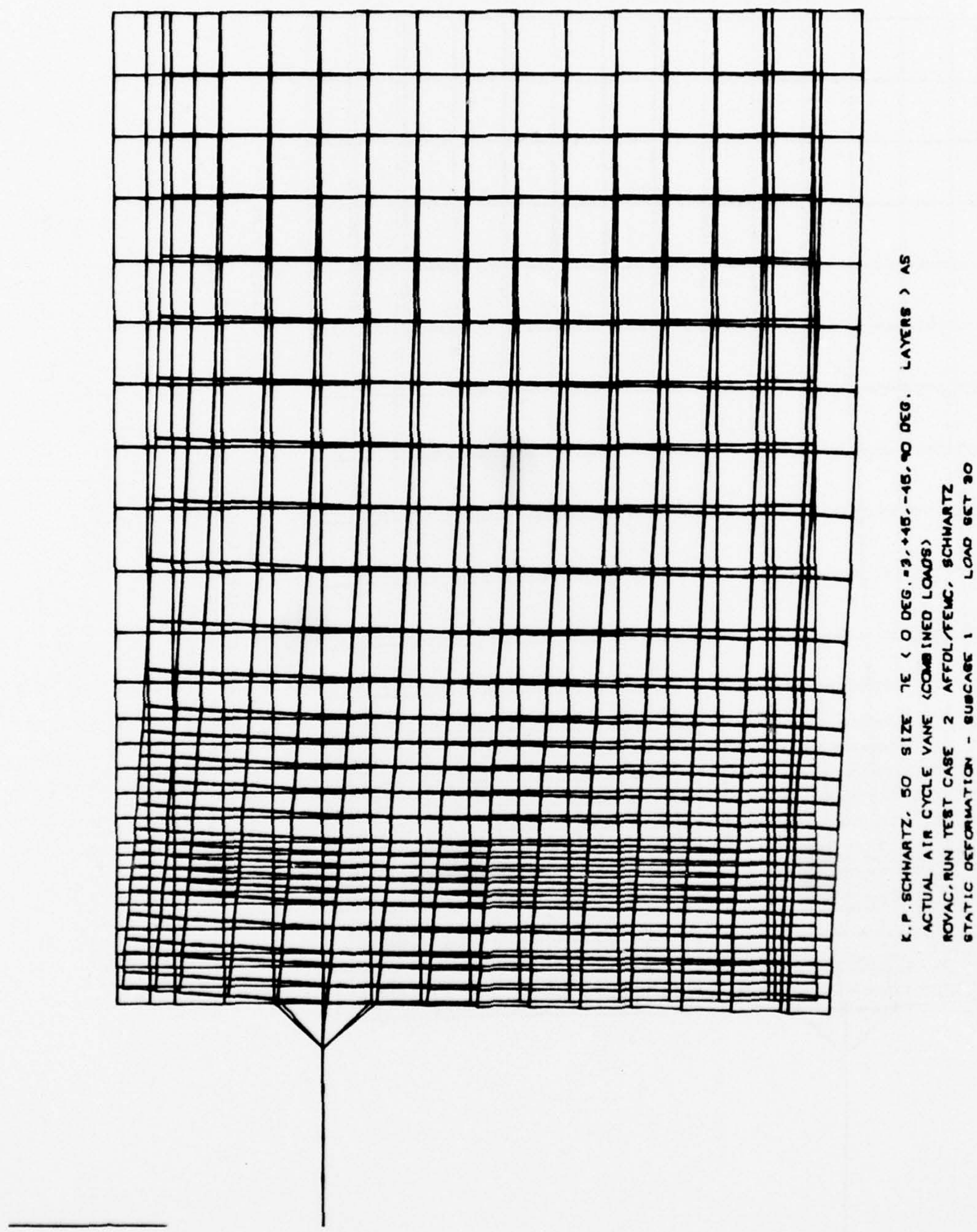

K.P.SCHWARTZ, ANALYSIS 10 (GRAPHITE COMPACT MATERIAL)
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC,RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 30


K.P.SCHWARTZ, NO AXLES 7A (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC,RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 30

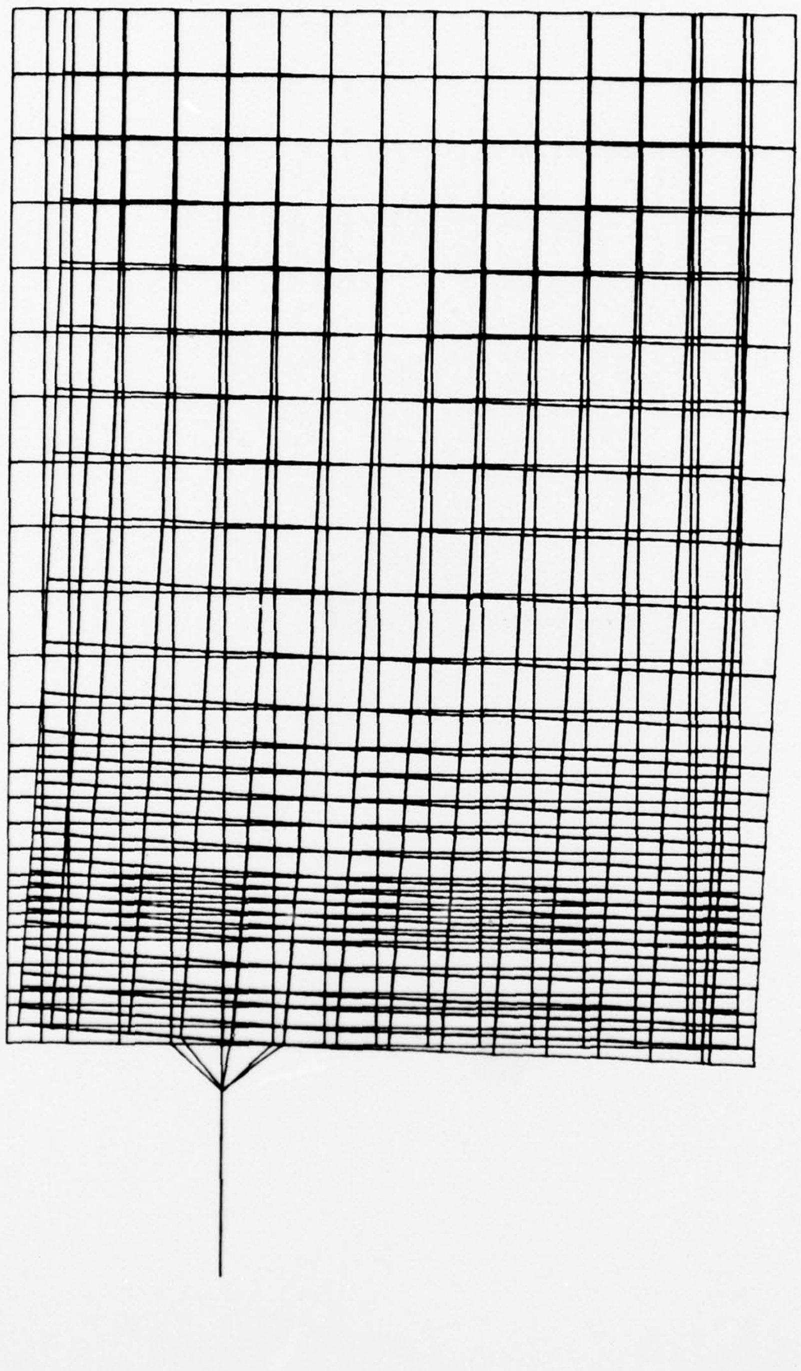

K.P.SCHWARTZ, NO BOOTS 7B (0 DEG.,=3,+45,-45,90 DEG. LAYERS) AS
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC,RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 30

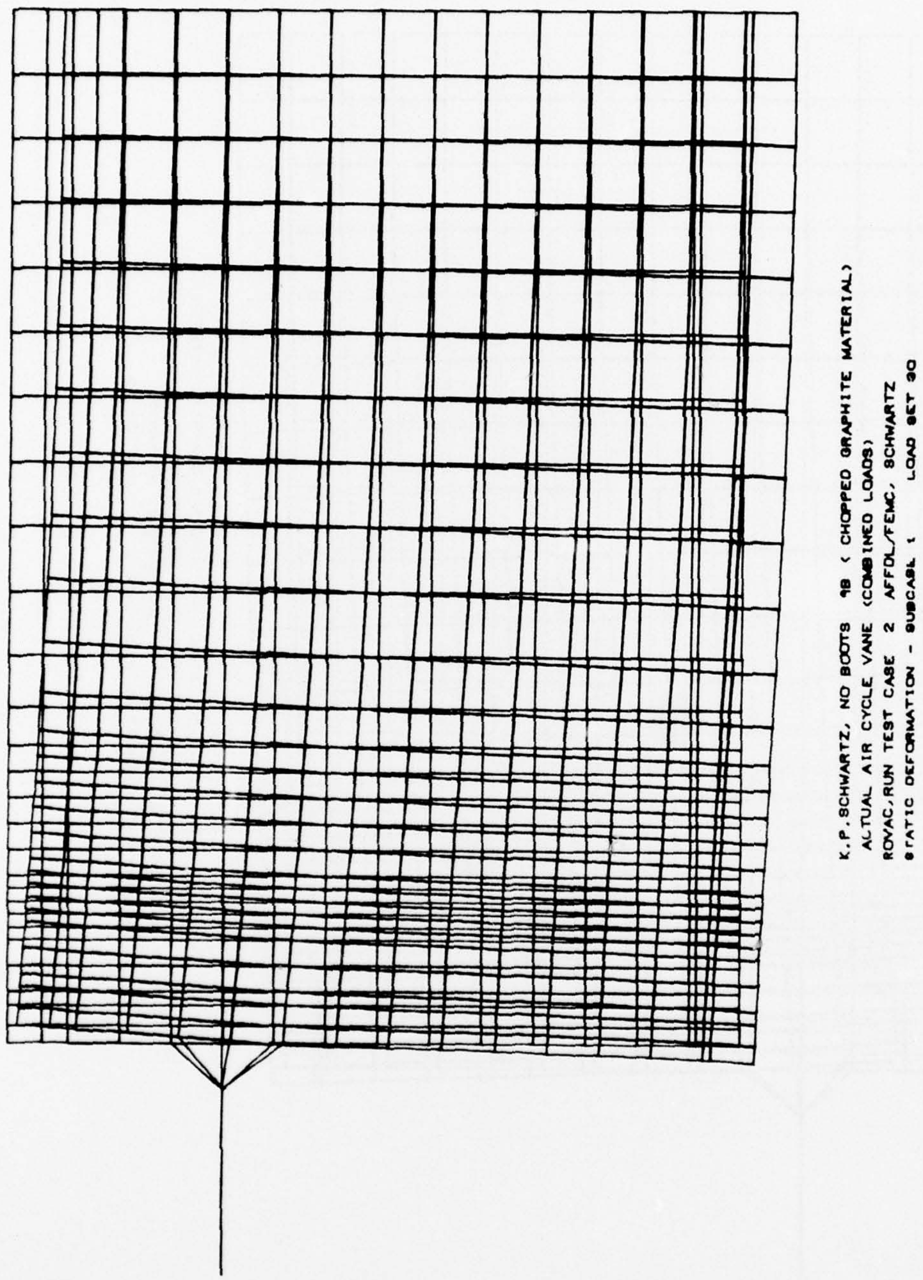

K.P.SCHWARTZ, 7O SIZE 7C (O DEG.=3,+45,-45,90 DEG. LAYERS) AS
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC,RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 30


K.P.SCHWARTZ, 8D SIZE 7D (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC,RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 20


K.P.SCHWARTZ, 5O SIZE 7E (0 DEG.=3,+45,-45,90 DEG. LAYERS) AS
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC,RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 30

7F not available


K.P.SCHWARTZ, NO AXLES 9A (CHOPPED GRAPHITE MATERIAL)
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC,RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 30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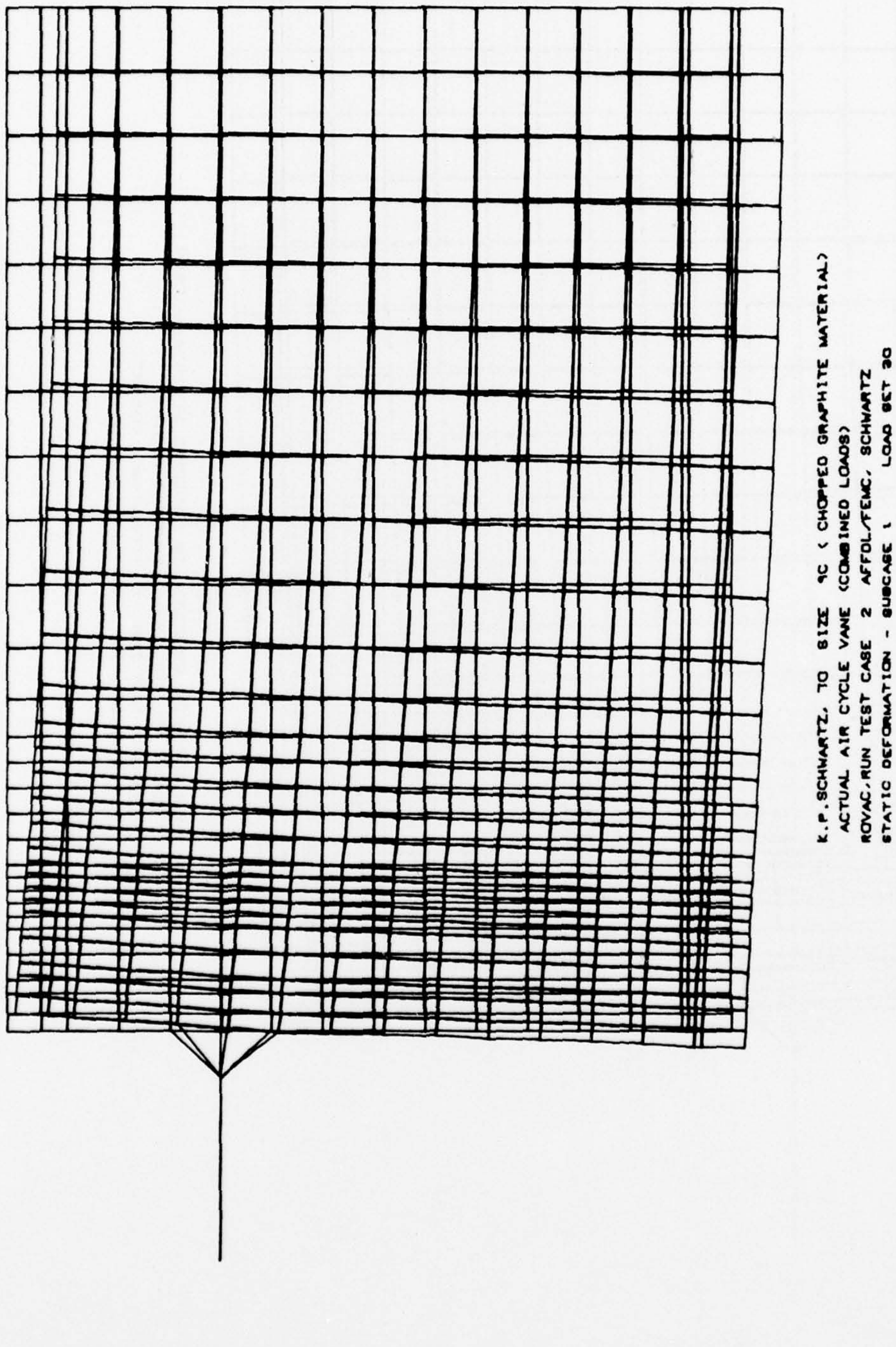
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC/RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 30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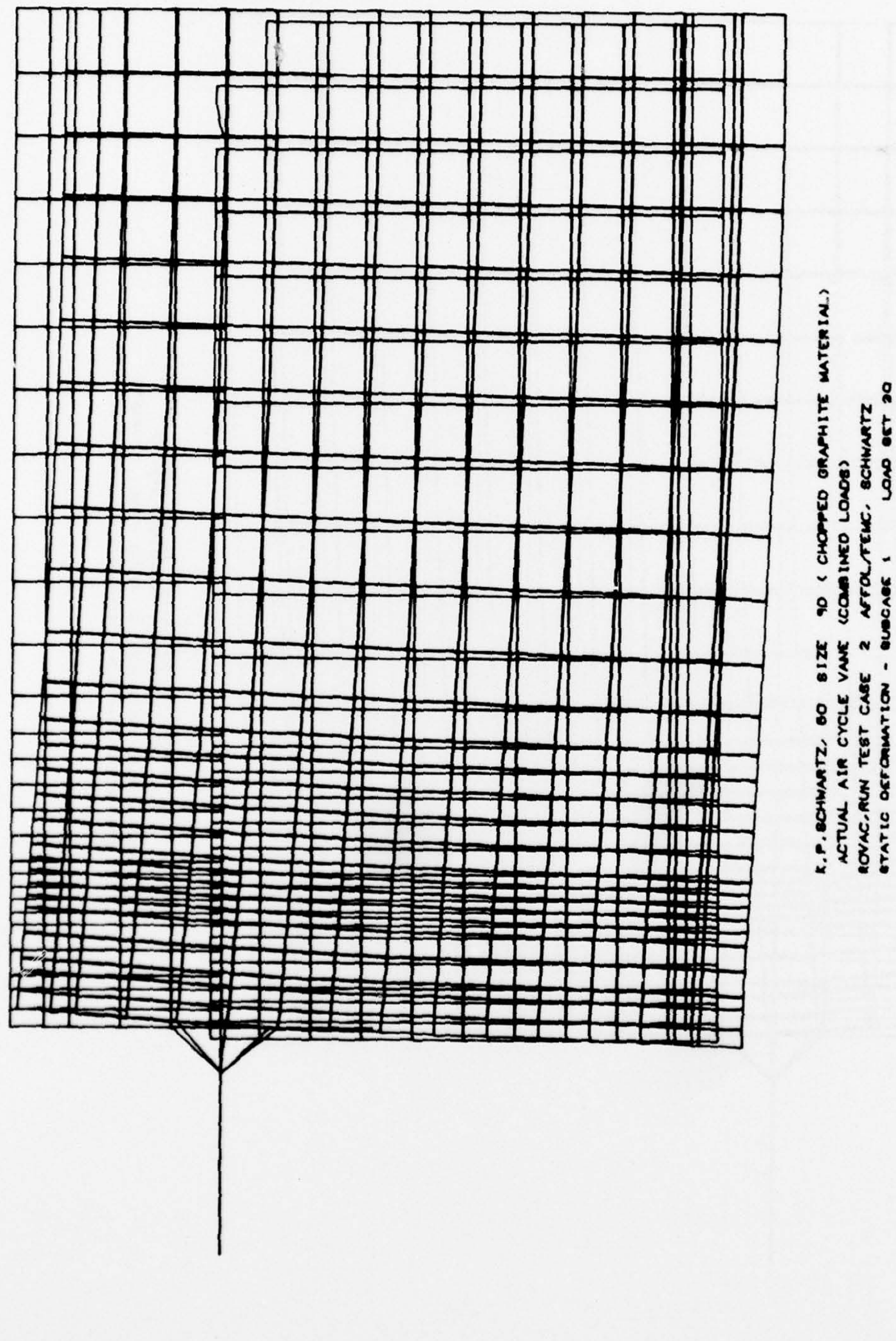
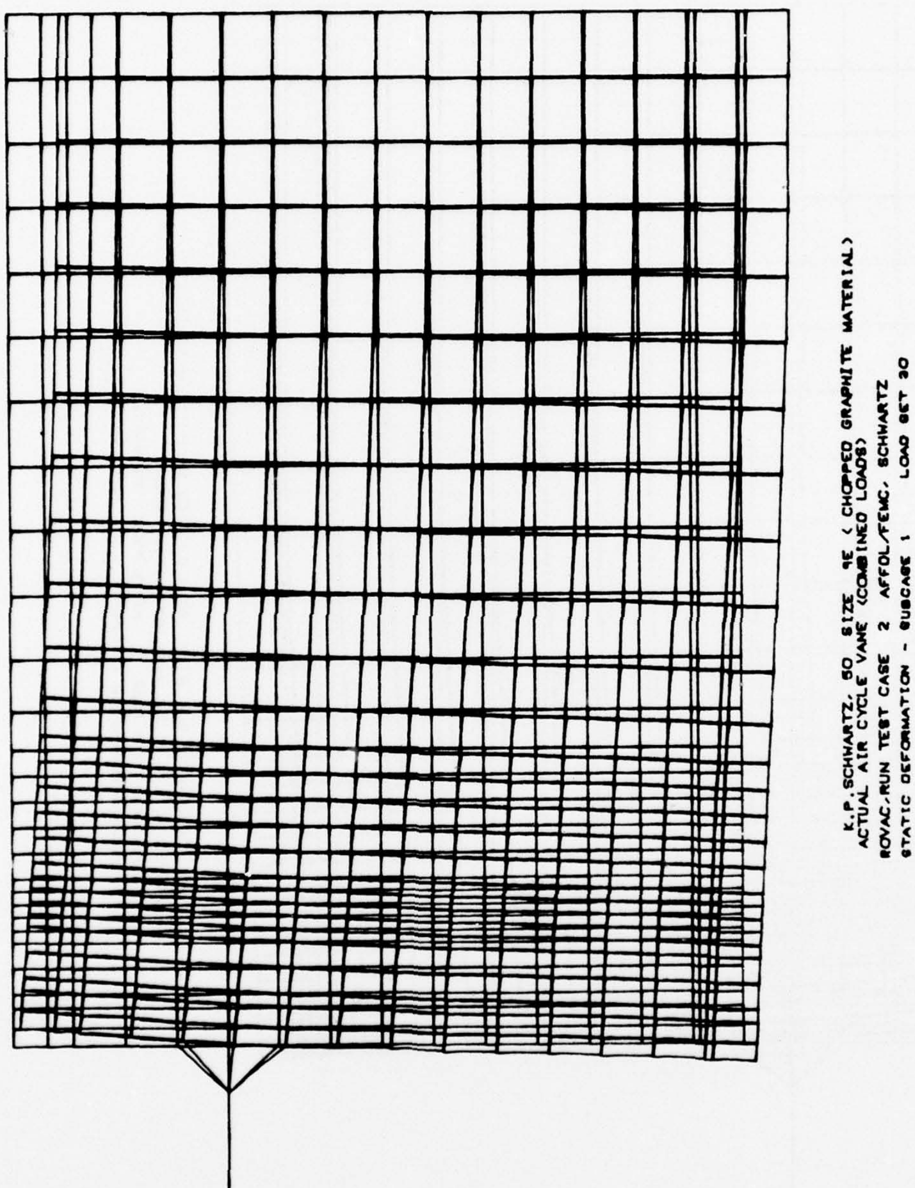
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC.RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 30


K.P.SCHWARTZ, 60 SIZE 90 (CHOPPED GRAPHITE MATERIAL)
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC.RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 20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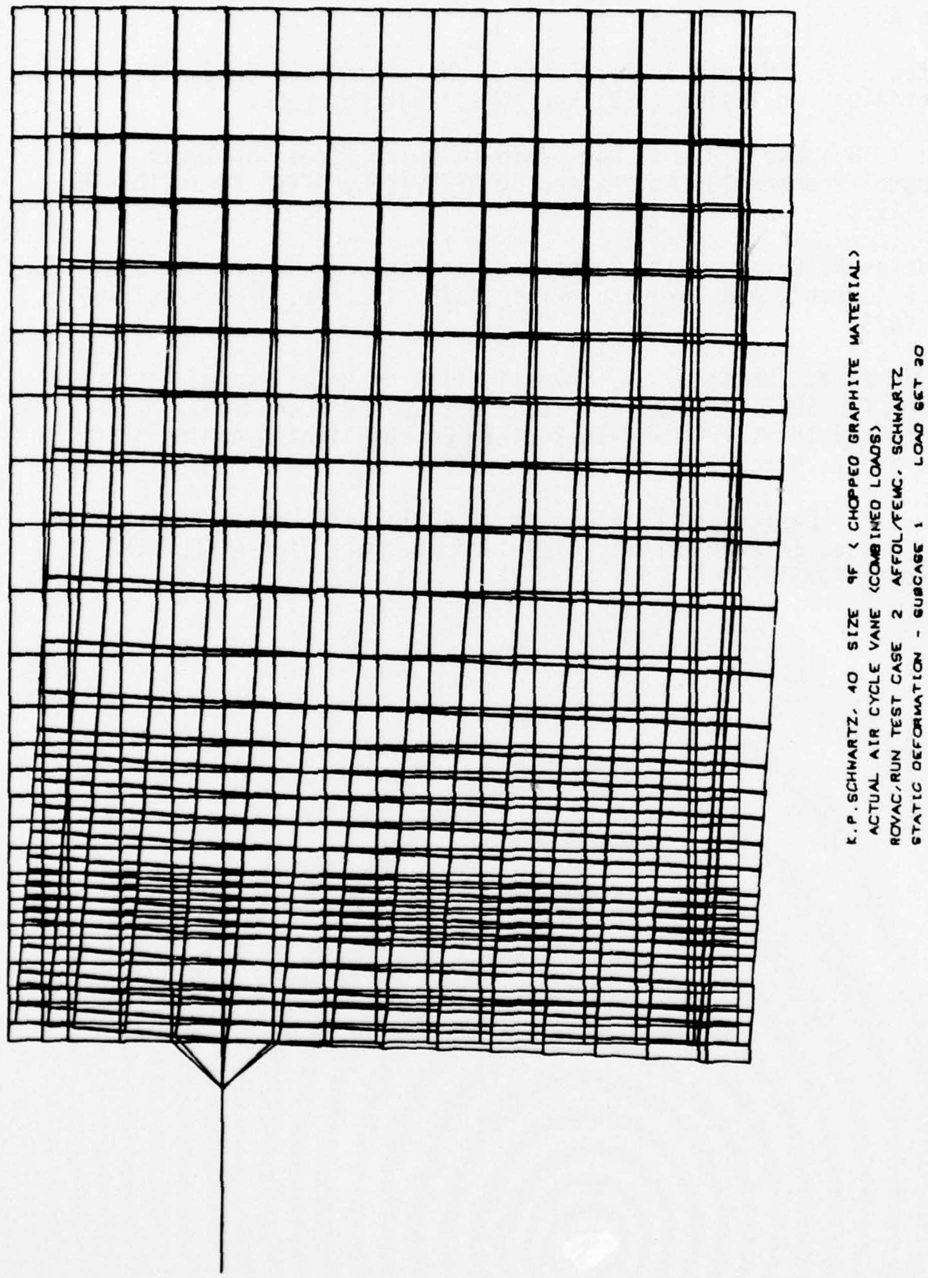
ACTUAL AIR CYCLE VANE (COMBINED LOADS)
ROVAC,RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 30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ACTUAL AIR CYCLE VANE <COMBINED LOADS>
ROVAC,RUN TEST CASE 2 AFFDL/FEMC, SCHWARTZ
STATIC DEFORMATION - SUBCASE 1 LOAD SET 20

REFERENCES

1. Advanced Composites Design Guide, Third Edition, January 1973, by LAD of Rockwell International Corp., Dr. L. H. Lackman (Program Manager)

2. Ashton J. E., Halpin J. C., Petit P. H., Primer on Composite Materials: Analysis, 1969, Technomic Publishing Co.

3. Muha T. J., Users Manual For Laminate Point Stress Analysis Computer Program SQ5 As Revised By AFFDL/FBL, AFFDL TM-74-107-FBL, July 1974

4. Randolph R. E., Graphite Composite Landing Gear Components-Side Brace Assembly And Torque Link For A37B Aircraft, AFFDL-TR-73-69, May 1973

5. Corwin P. W., White H. V., Investigation of Rotary-vaned Air Cycle Cooler for Small Remotely Located Heat Loads, Mechanical Technology Inc., AFFDL-TR-75-20, Air Force Flight Dynamics Laboratory, March 1975

6. Beiber M., Design and Development of A Graphite Epoxy Landing Gear Drag Brace, Interim Report, Cleveland Pneumatic for AFFDL/FEM, Contract F33615-75-C-3152

☆U.S.Government Printing Office: 1977 — 757-001/56